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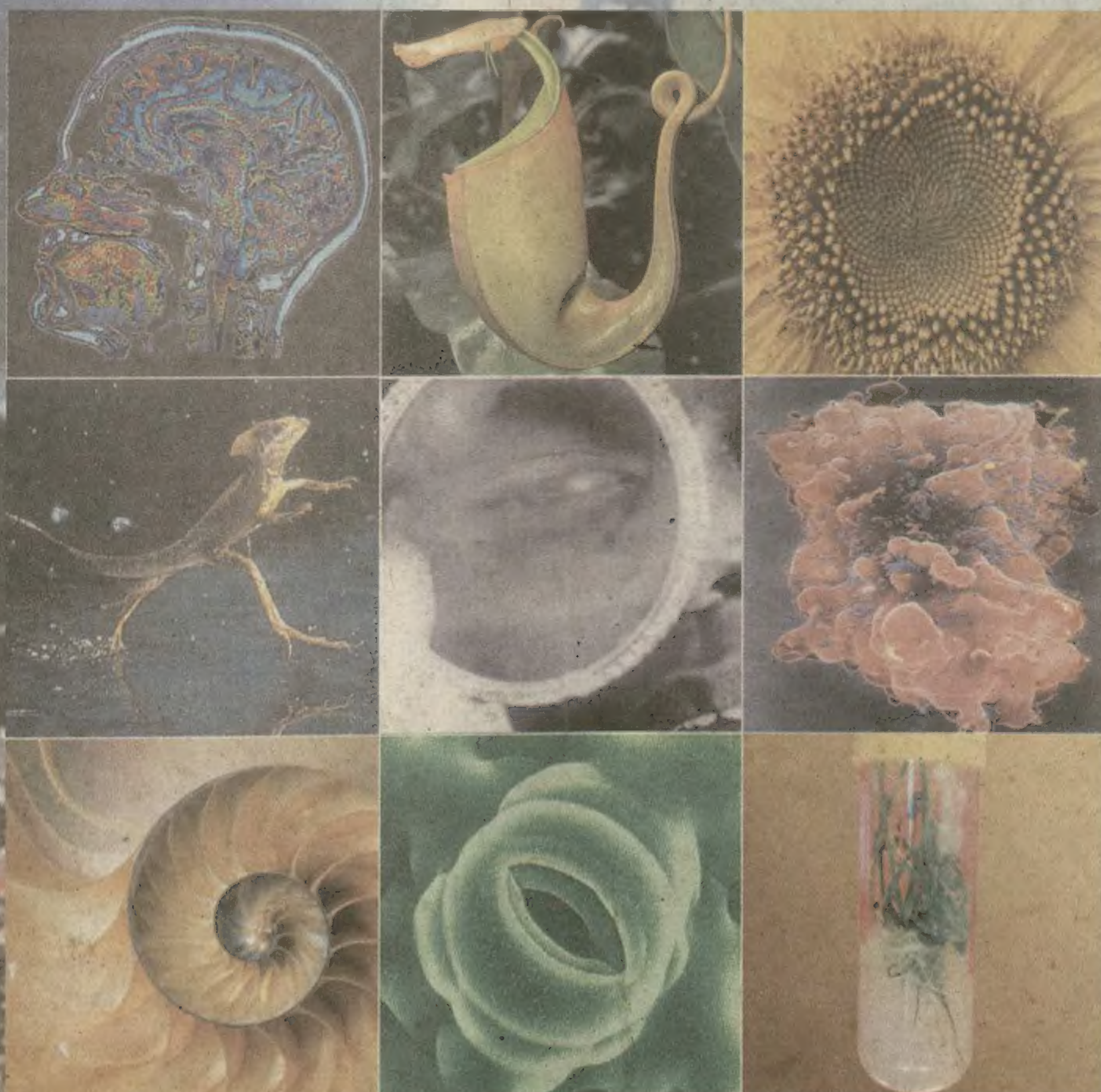
BIOLOGY

Textbook for Class XII



BIOLOGY

Textbook for Class XII

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PUBLISHER'S NOTE

The National Council of Educational Research and Training (NCERT) has been preparing and publishing school textbooks and other educational material for children and teachers. These publications are regularly revised on the basis of feedback from students, teachers, parents, and teacher educators. Research done by the NCERT also forms the basis for updating and revision.

This book is based on the National Curriculum Framework for School Education – 2000 and the syllabi prepared in accordance with it. The Executive Committee of the NCERT, in its meeting held on 19 July 2004, discussed all aspects related to the quality of textbooks and decided that the textbooks of all subjects should undergo a quick review. In pursuance of this decision, the NCERT constituted 23 Quick Review Committees to examine all the textbooks. These committees identified various errors of conceptual, factual and linguistic nature. The review process also took note of the evaluation of textbooks undertaken earlier. The exercise has now been completed and the errors identified have been corrected. We hope that this revised edition will serve as an effective medium of teaching and learning. We look forward to your suggestions to enable us to further improve the quality of this book.

SECRETARY
National Council of Educational
Research and Training

New Delhi
January 2005

CONSTITUTION OF INDIA
Preamble

WE, THE PEOPLE OF INDIA, having solemnly resolved to constitute India into a **SOVEREIGN SOCIALIST SECULAR DEMOCRATIC REPUBLIC** and to secure to all its citizens:

JUSTICE, social, economic and political;

LIBERTY of thought, expression, belief, faith and worship;

EQUALITY of status and of opportunity; and to promote among them all

FRATERNITY assuring the dignity of the individual and the unity and integrity of the Nation;

IN OUR CONSTITUENT ASSEMBLY this twenty-sixth day of November, 1949, do **HEREBY ADOPT, ENACT AND GIVE TO OURSELVES THIS CONSTITUTION.**

PREFACE

Living organisms are extremely complex functioning systems. An important group of these consists of plants, which have the capability to synthesise organic compounds from two basic raw materials, water and carbon dioxide, using the energy trapped from sunlight. The plants must have the capacity to access water and minerals from soil, carbon dioxide from the atmosphere, and energy from sunlight. They must be able to transport water, minerals and processed organic compounds to different parts of their body. Existence of all other organisms depends on this capability of plants, but the organisms that derive their food directly or indirectly from plants, need to have mechanisms to digest this food and eliminate the toxic wastes.

The organisms must possess the ability to move. The movement ranges from that of the subcellular particles to organs to organism as a whole. The organisms must also possess the capability to grow and develop in an orderly manner, to reproduce and to supply all the essential requirements to each cell, tissue and organ. They must be able to respond to changes in their physical and chemical environment. They must retain the integrity of their structure and functioning under a wide range of conditions to which they are likely to be exposed. The organisms must adapt their structure and modify life processes, over generations, to be able to occur and reproduce in varied environments.

To drive all the life processes, organisms need energy, and this they get by breaking down the complex organic molecules largely through oxidation-reduction reactions. A substantial portion of energy so released is trapped in chemical form, and the carbon skeletons are used for elaboration of other important compounds necessary for life activities.

All the capabilities and processes needed to sustain and perpetuate life are based on an intricate and diverse set of physiological mechanisms which are outlined in this book.

Organisms seldom occur as isolated individuals. They are organised into populations and biological communities, which have their unique set of characteristics and properties. An integration of the biological community with the non-living factors of the environment through the processes of energy flow and nutrient cycling results into an ecosystem which is structurally well organised and functions as a unit of nature. Organisms, communities, ecosystems, and environment which constitute an unique set of natural resources for humans are under tremendous pressure due to expansion of human population and resultant over-exploitation and pollution. The human impact has reached an alarming level and is resulting into loss of biodiversity and other undesirable global changes. All of the above are dealt within the science of ecology and are briefly discussed in this book.

Notwithstanding the above, humans themselves comprise an unique resource and have endeavoured to use the techniques and tools of the modern science for generation and improvement of biological resources for their welfare. The last Unit of the book outlines some of the ways in which the knowledge of biology is used for promoting the human welfare.

I thank the Director, NCERT for encouragement and for giving us the opportunity to serve this national endeavour.

I also thank the Head and Dean, Department of Education in Science and Mathematics, NCERT, for keen interest and sustained support during the preparation of this book.

I would like to express my sincere appreciation and thanks to all the members of the writing team for their devotion to this endeavour. My colleagues at the Banaras Hindu University provided valuable inputs in various chapters. I also thank the Indian Institute of Remote Sensing for helping with some of the figures. The Coordinator of this textbook, took special pains to see that the writing and the publication of the book proceeds smoothly.

We would welcome comments and suggestions from the students and teachers for further improvement of the textbook.

J.S. Singh
Chairman
Writing Team

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CONSTITUTION OF INDIA

Part IV A (Article 51 A)

Fundamental Duties

Fundamental Duties – It shall be the duty of every citizen of India —

(a) to abide by the Constitution and respect its ideals and institutions, the National Flag and the National Anthem;

(b) to cherish and follow the noble ideals which inspired our national struggle for freedom;

(c) to uphold and protect the sovereignty, unity and integrity of India;

(d) to defend the country and render national service when called upon to do so;

(e) to promote harmony and the spirit of common brotherhood amongst all the people of India transcending religious, linguistic and regional or sectional diversities; to renounce practices derogatory to the dignity of women;

(f) to value and preserve the rich heritage of our composite culture;

(g) to protect and improve the natural environment including forests, lakes, rivers, wildlife and to have compassion for living creatures;

(h) to develop the scientific temper, humanism and the spirit of inquiry and reform;

(i) to safeguard public property and to abjure violence;

(j) to strive towards excellence in all spheres of individual and collective activity so that the nation constantly rises to higher levels of endeavour and achievement;

(k) who is a parent or guardian, to provide opportunities for education to his child or, as the case may be, ward between the age of six and fourteen years.

CONSTITUTION OF INDIA

Part III (Articles 12 – 35)

(Subject to certain conditions, some exceptions and reasonable restrictions)

guarantees these

Fundamental Rights

Right to Equality

- before law and equal protection of laws;
- irrespective of religion, race, caste, sex or place of birth;
- of opportunity in public employment;
- by abolition of untouchability and titles.

Right to Freedom

- of expression, assembly, association, movement, residence and profession;
- of certain protections in respect of conviction for offences;
- of protection of life and personal liberty;
- of free and compulsory education for children between the age of six and fourteen years;
- of protection against arrest and detention in certain cases.

Right against Exploitation

- for prohibition of traffic in human beings and forced labour;
- for prohibition of employment of children in hazardous jobs.

Right to Freedom of Religion

- freedom of conscience and free profession, practice and propagation of religion;
- freedom to manage religious affairs;
- freedom as to payment of taxes for promotion of any particular religion;
- freedom as to attendance at religious instruction or religious worship in educational institutions wholly maintained by the State.

Cultural and Educational Rights

- for protection of interests of minorities to conserve their language, script and culture;
- for minorities to establish and administer educational institutions of their choice.

Right to Constitutional Remedies

- by issuance of directions or orders or writs by the Supreme Court and High Courts for enforcement of these Fundamental Rights.

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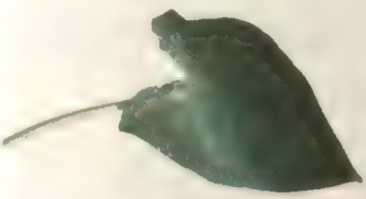

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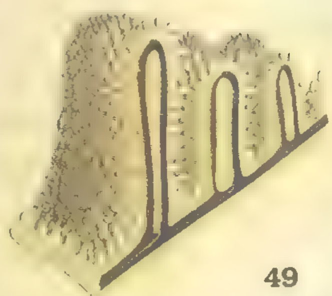
PHYSIOLOGY OF ANIMALS



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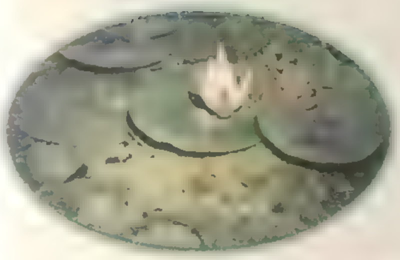

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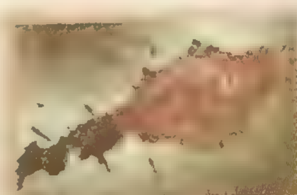
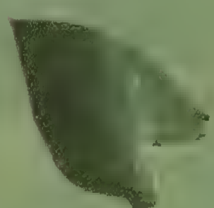


UNIT SIX

PHYSIOLOGY OF PLANTS



Plants germinate from seeds, grow, develop, mature, reproduce and die. Plant physiology is the study of these processes. In other words, plant physiology deals with how plants function. Plants are autotrophs and make their own food by utilising carbon dioxide, water and sunlight. But before plants become photosynthetically competent after the emergence of leaves, the germinating plants get their food from reserves in the cotyledons, as in peas and beans. As the plant grows, the role of food production is shifted from cotyledons to fully exposed leaves, which take a variety of shapes and sizes and carry out the process of photosynthesis. It is said that "only the sun gives without taking." And plants play a big role in this process. The sun energy is converted to ATP, which is necessary for conversion of carbon dioxide to carbohydrates. The carbohydrates (glucose, sucrose or starch) are utilised in respiration by plants themselves (and also by animals which eat plants) to form ATP that provides the energy necessary for life's function. The process of respiration that produces ATP uses oxygen that is released during photosynthesis. It is this oxygen that changed the atmosphere from one full of hydrogen to one rich in oxygen. Plants possess the capability of taking up nitrogen and other nutrients, along with water, from the soil through an elaborate root system. The inorganic and organic nutrients act as building blocks and help plants grow and reproduce. All these activities in plants, like any other living organism, follow the known chemical and physical laws.

Melvin Calvin

(1911-)

Calvin born in Minnesota in April, 1911 received his B.S degree from Michigan College of Mining and Technology (now Michigan Technological University) and Ph.D. in Chemistry from the University of Minnesota. He served as Professor of Chemistry at the University of California, Berkeley.

He has served on many scientific boards for the U.S. Government. Active in many professional societies, Calvin served the Royal Society of London, which awarded him the Davy Medal in 1964 for his pioneering work in chemistry and biology, particularly the photosynthesis studies.

His clear understanding of the nature of organic molecules proved valuable in his subsequent work in biological chemistry. Investigations of complex organic chemical systems using radio isotope C^{14} as a tracer by his team were published as techniques in *Isotopic Carbon* (1949).

He along with J.A. Bassham studied reactions in green plants forming sugar and other substances from raw materials like carbon dioxide, water and minerals by labelling the carbon dioxide with C^{14}. These were described in *The Path of Carbon in Photosynthesis* (1957) and *The Photosynthesis of Carbon Compounds* (1962). Calvin proposed that plants change light energy to chemical energy by transferring an electron in an organised array of pigment molecules and other substances. This was substantiated by research not only in his laboratory but also elsewhere later on. The mapping of the pathway of carbon assimilation in photosynthesis earned him Nobel Prize in 1961.

The principles of photosynthesis as established by Calvin are, at present, being used in studies on renewable resource for energy and materials and basic studies in solar energy research. In addition, he is also engaged in studies of chemical carcinogenesis studying the molecular mechanisms of transformation of normal cells to malignant cells and the synergism between chemical and viral carcinogenesis. This study has indicated that chemicals act by triggering the integration of oncogenic information already present in the cell.

Chapter 1

Plant-Water Relations

Water is essential for all physiological activities of plants. It acts as an excellent solvent and helps in the uptake and distribution of mineral nutrients and other solutes required for growth and development. Water also plays a direct role in many useful reactions operating in cells. For example, water plays a key role in photosynthesis and acts as a source of oxygen.

You know that cells are structural and functional units of all organisms. In plants, cells are composed of cell wall and protoplast. The term **protoplast** is used to refer collectively to the plasma membrane and protoplasm. The protoplasm refers to the living contents of cells and consists of cytoplasm and a nucleus. It is useful to consider the cell as having three compartments : the vacuole, protoplasm and the cell wall. The compartments are separated from each other by plasma membranes, the tonoplast lying between the vacuole and the protoplasm, and the plasmalemma between the protoplasm and the cell wall. You also know that in many tissues, plasmodesmata connect the protoplasm of one cell to that of the next. The plasma membrane is selectively permeable, which means it allows some materials to pass through it but not others. Also, a continuous path for water exists from the soil through the root, stem, leaf, and into the atmosphere. This chapter covers absorption and movement of water within and between cells, its translocation from root to leaf to atmosphere, transpiration and stomatal movements.

1.1 Water Potential

All living organisms, including plants, require free energy to grow and reproduce. In thermodynamics, free energy represents the potential to do work. The potential energy of water is referred to as **water potential**. That water has potential energy, can be exemplified by water stored behind a dam. As this water runs downhill, its potential energy can be converted to electrical energy by making the water fall on turbines. Similarly, pressure is another source that provides energy to water. The increasing pressure increases the free energy and, hence, the water potential in a system.

Can we move the water up against gravity? Yes, we can, but only when pressure is applied by pressure. This means that water moves from the point where water potential is greater, to the other point where water potential is less. It can also be said that the difference in water potential between two points is a measure of the amount of work (*energy*) needed to move water from one point to the other. Therefore, based on the concept of water potential, it is easier for the scientists to predict the way in which the water will move. Water potential is measured in terms of pressure. The common measurement unit of water potential is pascal, Pa (1 Megapascal, Mpa = 10 bars), and is represented by the Greek letter, Psi (ψ).

It is measured in relative quantity, and expressed as the difference between the potential of a solution in a given state and the potential of the same solution in a standard state. Water potential is influenced by three factors : concentration, pressure, and gravity. Thus, water potential, ψ_w, of any

solution can be represented as individual components as per the following equation :

$$\psi_w = \psi_s + \psi_p + \psi_g$$

Each component, ψ_s, ψ_p and ψ_g denotes, respectively, the effects of solutes, pressure, and gravity. Note that pure water has a higher potential than the water inside a cell. Theoretically, ψ_w of the pure water is taken as zero and, therefore, ψ_w inside plant cells is negative.

The term, ψ_s, is called **solute potential** or **osmotic potential**. Solutes present in a cell (or in any solution) reduce the free energy of water, or the water potential.

The term, ψ_p, is called **pressure potential** or **hydrostatic pressure** of a solution. If the pressure is positive, ψ_w will be raised and if the pressure is negative, ψ_w will be reduced. The positive hydrostatic pressure is called **turgor pressure** and can keep on incresing till the cell becomes fully turgid. At this stage the cell wall prevents the protoplast from increasing in size and exerts a pressure called **wall pressure**. The ψ_p for pure water in an open beaker is zero. The term, ψ_g, called **gravity potential**, denotes the effect of gravity on water potential. It depends on the height of water above the reference state of water, the density of water, and the acceleration due to gravity. If the vertical distances are small (less than 5 meters), the ψ_g is negligible and, hence, ignored.

In a plant cell, only ψ_s and ψ_p are important, and thus, the above equation is simplified as :

$$\psi_w = \psi_s + \psi_p$$

If the solute concentration is increased inside the cell, the ψ_s is lowered, and thus, the ψ_w is decreased. This allows water to move into the cell from outside due to a water potential gradient. As water moves into the cell from outside, the hydrostatic pressure (ψ_p) increases. This results in an increased ψ_w of the cell, and the difference between the inside and the outside ψ_w ($\Delta\psi_w$) is reduced. Water will move out of the cell if it is placed in a solution that has lower ψ_s or ψ_w.

1.2 Absorption and Movement of Water

Absorption of Water

Roots absorb water in plants. Root hairs present on the root make a contact with soil particles and absorb water from the soil. Root hairs are the outgrowths of the epidermal cells which increase the water absorbing surface area of the roots. From root hair, the water moves through the root cortex and to the xylem elements. Water in the root moves through two pathways :

(i) **apoplast pathway**, and

(ii) **symplast pathway**.

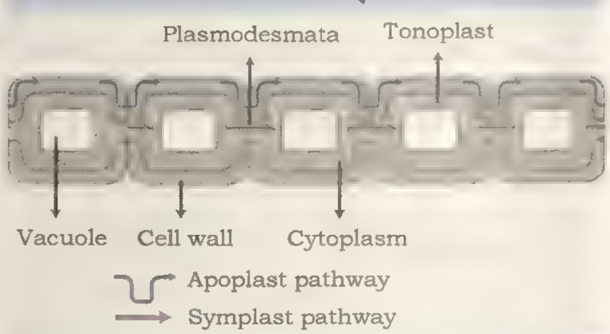


Fig. 1.1 *The pathways of water movement*

The apoplastic movement of water occurs exclusively through the cell wall without crossing any membranes, while the symplastic movement occurs from cell to cell through the **plasmodesmata**, as shown in Figure 1.1. The symplast comprises the network of cytoplasm of all cells inter-connected by plasmodesmata.

Major proportion of water flow in the root cortex occurs via the apoplast, as the cortical cells are loosely packed, and thus, the cortex offers no resistance. The apoplastic water movement beyond the cortex is blocked by the casparian strip present in the endodermis (Fig. 1.2). The casparian strip is composed of a wax-like substance called **suberin**, which blocks water and solute movement through the cell wall of the endodermis. Thus, beyond endodermis, water is forced to move through the cell membranes and cytoplasm (Symplastic pathway). This movement of water through

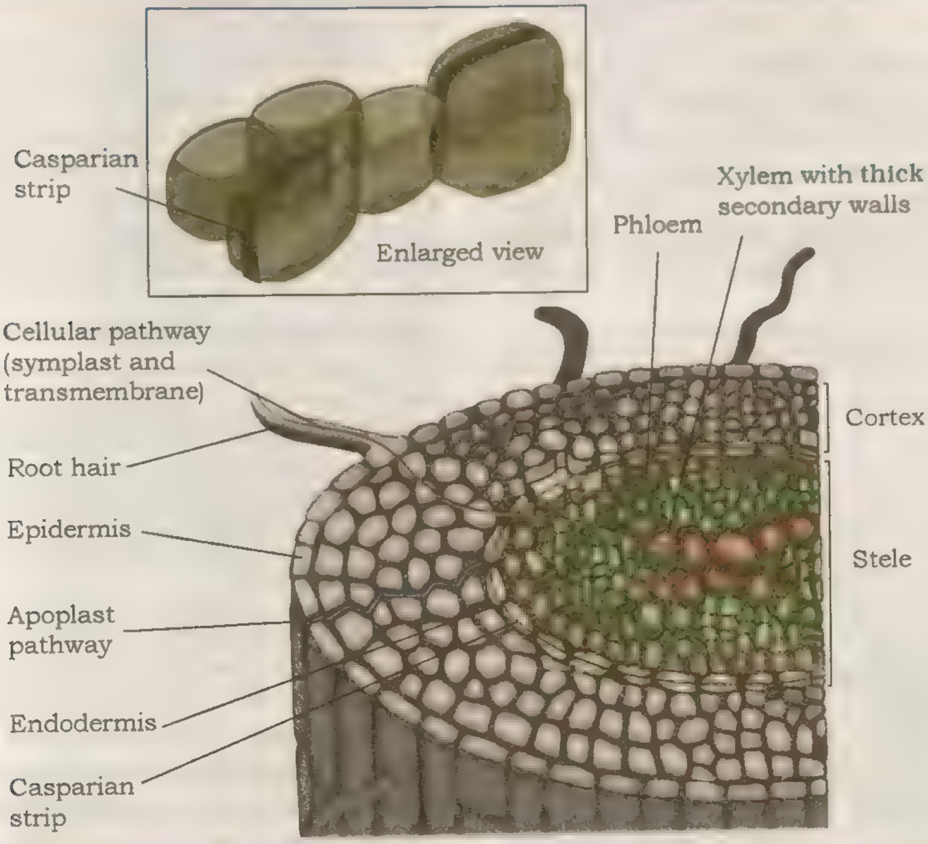


Fig. 1.2 *Water movement from root hair to the cortex and to the xylem vessels, showing the apoplast pathway and the cellular pathway through symplast and transmembrane. The casparian strip present in the endodermis is shown in an enlarged view*

the cell membrane is called **transmembrane pathway**. In this pathway, water may also cross through the **tonoplast** surrounding the vacuole. Once the water reaches root xylem, transpiration drives the water to move to the leaves through the stem.

Diffusion

Diffusion is a random movement of individual molecules from a region of higher concentration to a region of lower concentration. Larger the difference in concentration, more rapid is the flow of molecules. Diffusion is more rapid in gases than in liquids. When there is no net movement of molecules, a state of equilibrium is reached. In diffusion, the movement of molecules is random and independent of each other.

Uptake and distribution of water, gases and solutes occur in the plants as a result of diffusion, for example, supply of carbon dioxide from atmosphere to the leaves for photosynthesis, and loss of water vapour from leaves to the atmosphere.

Permeability

The extent to which a membrane permits or restricts the movement of a substance is called **membrane permeability**. It depends on the membrane composition, as well as the chemical nature of the solute. Permeability can be measured readily by determining the rate at

which solute passes through a membrane under a specific set of conditions.

Osmosis

Diffusion of water through a semi-permeable membrane is known as **osmosis**. The diffusion of water molecules continues to occur across the membrane until an equilibrium is reached. At equilibrium, the water potential on both sides of the membrane is equal. Osmosis can be demonstrated by a simple experiment, as shown in Figure 1.3.

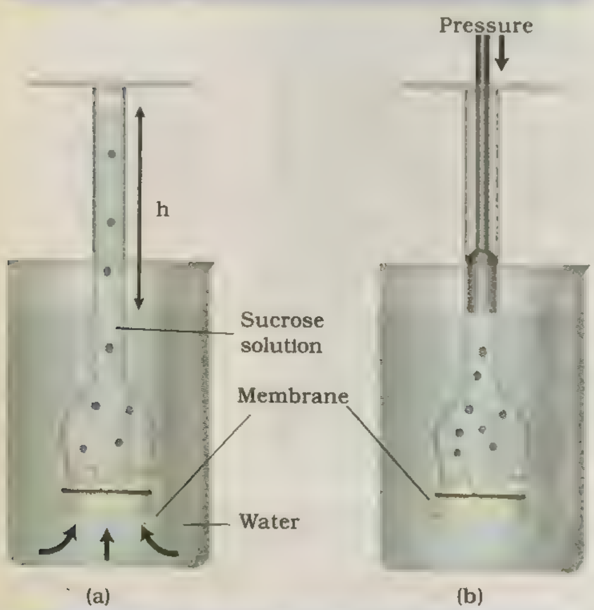


Fig. 1.3 *A demonstration of osmosis. A thistle funnel is filled with sucrose solution and kept inverted in a beaker containing water. (a) Water will diffuse across the membrane (as shown by arrows) to raise the level of the solution in the funnel (b) Pressure can be applied as shown to stop the water movement into the funnel*

In this experiment, the water contained in a beaker is separated from a solution in a thistle funnel by a semi-permeable membrane. (This kind of membrane can be obtained from an egg.) Water will continue to move across the membrane, resulting in the rise of the solution in the funnel until an equilibrium is reached. Pressure can be applied to the solution from the upper part of the funnel to prevent the movement of water into it through the membrane. The pressure required to stop the movement of water completely is called **osmotic pressure**. It is also referred to as **osmotic potential** or **solute potential**. Osmotic pressure and osmotic potential are numerically equal, but osmotic potential has a negative sign. The magnitude of the osmotic pressure is a function of solute concentration in a solution. It should be noted that water not bounded by any membrane, has no osmotic pressure. It has only the potential to result into a pressure when placed in an osmometer. That is why a solution has an osmotic potential (ψ_s), which is the negative of osmotic pressure (π; pi), that is :

$$\psi_s = -\pi$$

If additional pressure is applied (more than the osmotic pressure applied to prevent the flow of water into the solution in the funnel in the above experiment), then water can be made to flow out of the solution into the water in the beaker. This process is called **reverse osmosis**. The process of reverse osmosis is used for removing salts from saline water. Osmosis is driven by two factors :

(i) concentration of dissolved solutes in a solution, and
(ii) pressure difference.

Both these factors determine the chemical potential of water, which is the driving force for water movement in plants. Water moves from a region of high chemical potential of water to a region of low chemical potential of water. The chemical potential of water is also known as water potential and represents the free energy associated with water.

Plasmolysis

If a turgid plant cell (cell with positive turgor pressure) is placed in a solution that has more solutes, it exerts a higher osmotic pressure, and water will move out of the cell by osmosis. This will cause vacuole and protoplast to shrink, resulting the plasma membrane to fold inward and move away from the cell wall, as shown in

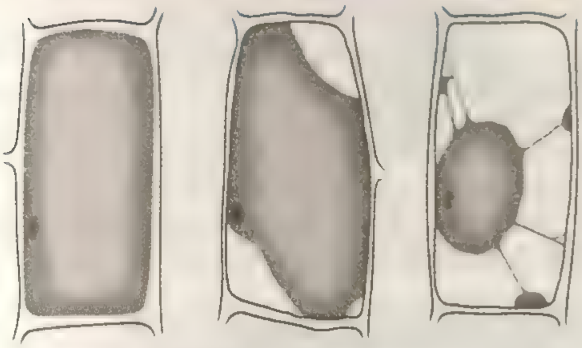


Fig. 1.4 *Plasmolysis in an epidermal cell of a leaf. (a) cell under normal conditions (b) cell when placed in a strong sucrose solution, plasma membrane starts contracting (c) cell when placed in a more concentrated solution loses lot of water and contracts much more*

Figure 1.4. This is called **plasmolysis**. Continuous loss of water from plant cells results in wilting and drooping of leaves and stems.

Imbibition

Imbibition is a type of diffusion by which movement of water takes place along a diffusion gradient. An adsorbant (for example, cellulose matrix) is required for the imbibition to occur. Dry plant material or seeds act as adsorbant to imbibe water and swell. The swollen seeds produce a large pressure developed by imbibition. This pressure makes the seedlings to emerge above the ground through the soil surface. The pressure, called **imbibition pressure**, is also known as **matric potential** (i.e. water potential of the matrix) in the context of plant-water relations.

Two conditions are necessary for the imbibition to take place. They are :

(i) water potential gradient between the surface of the adsorbant and the liquid imbibed, and
(ii) affinity between the adsorbant and the imbibed liquid.

Dry seeds have a highly negative water potential. When these seeds are placed in water ($\psi_w = 0$), a steep water potential gradient is established. This allows rapid movement of water to the surface of the dry seeds. The imbibition of water into seeds continues until an equilibrium between the water outside and in the seed is reached.

1.3 Theories of Water Translocation

How can water move to the top of a tree which may be more than 100 m high? Different theories have been put forth to explain this. The three most prominent theories are :

(i) Root Pressure
(ii) Capillarity
(iii) Cohesion Theory

Root Pressure

Water from the soil is absorbed by root hairs and is conducted through xylem vessels. If the stem of a plant is transversely cut above the soil surface, xylem sap will exude in the form of a drop from the cut surface. This indicates the presence of a positive pressure in the xylem. This pressure is known as **root pressure**.

Mineral ions from the soil are taken up by roots and get deposited in the xylem vessels. Accumulation of ions leads to the lowering of osmotic potential. This, in turn, results in lowered water potential in the xylem vessels. The low water potential of the xylem sap compared to that of the soil solution attracts water, which is taken up inside the roots. Remember, that water flows from a region of high water potential to a region of low water potential.

Capillarity

The uptake of water through xylem vessels is also possible in small-sized plants through capillarity. Capillarity refers to a rise in water in tubes of small diameter kept in a vessel containing water. This rise in water is due to the forces of adhesion and cohesion. Adhesive forces attract molecules of different kinds, whereas cohesive forces attract molecules of the same kind to each other. Force of gravity also affects water uptake by capillarity.

According to this theory, water is first taken in due to the force of adhesion between water and the walls of thin xylem vessels (tracheids).

As the water flows upward along the wall, strong cohesive forces between water molecules come into play to pull the water upward. This upward pull of water continues until the forces of adhesion and cohesion are balanced by the downward force of gravity.

Cohesion Theory

Cohesion theory is the most accepted theory of water movement through plants. This theory was given by Henry Dixon in 1914. As the name suggests, the Cohesion theory is based on the force of cohesion between water molecules. This allows formation of a continuous water column throughout the plant, that is, from the top of the plant down to the root tip. According to this theory, evaporation of water from the leaf to the atmosphere results in a decrease in the water potential of the epidermal cells, which are in direct contact with the atmosphere. The water lost from these cells is replaced by the water moving from the adjacent cells along a water potential gradient. The water lost from leaf cells is, responsible for generating a negative ψ_w in the xylem elements creating a tension or transpiration pull. As a result water movement forms a continuous water column from roots to the leaves due to cohesive and adhesive properties of water molecules. Also, the walls of xylem vessels, made up of ligno-cellulose, have strong affinity for water molecules. The water potential of root cells being lower than the water potential of soil, movement of water occurs from soil to the roots. Uptake of water, as described by the Cohesion theory, is also referred to as **transpirational pull** (Fig. 1.5).

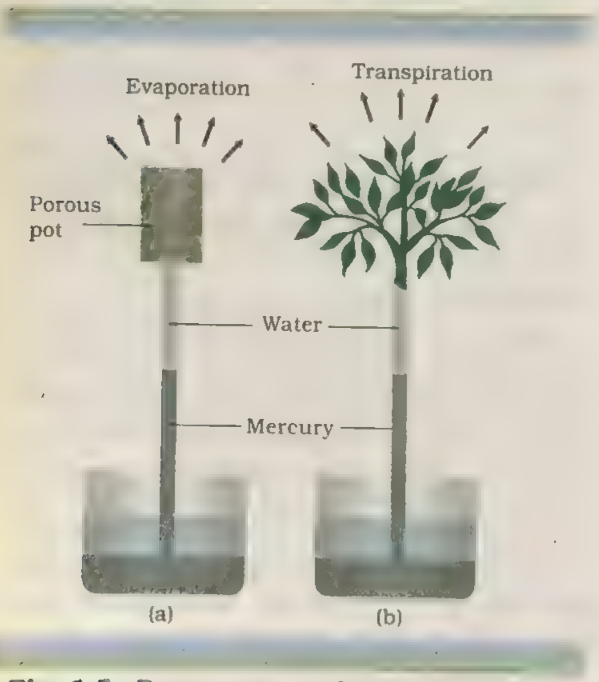


Fig. 1.5 *Demonstration of Cohesion theory of water translocation (a) Evaporation; and (b) Transpiration*

1.4 Transpiration

Loss of water in the form of water vapour from the plant to the atmosphere is known as transpiration. About 90 per cent of the total transpiration occurs from leaves. Leaf surfaces, both upper and lower, contain small pores, called **stomata**, through which water is transpired to the atmosphere. The stomatal pores open into the intercellular spaces of the leaf and provide an uninterrupted path from the interior of the leaf to the external environment (Fig. 1.6).

Significance of Transpiration

If the transpirational loss of water is higher than the amount of water absorbed by the roots from the soil, plants undergo water stress. This results in decline of growth in plants. The question is, then why transpiration is important and what is its significance. Transpiration helps in the movement of xylem sap, which simultaneously increases the absorption of mineral nutrients by the roots from the soil. As the evaporation causes cooling, it assists in the cooling of leaves. Not all the solar radiations absorbed by leaves are used in photosynthesis, but some will cause warming of the leaves. Transpiration, however, reduces the heating of the leaves.

Factors affecting Transpiration

Transpiration is affected by three environmental factors, that is, humidity, temperature and wind speed. These factors influence the rate of water diffusion from the leaves to the atmosphere.

If the humidity is high, water is lost slowly into the air as a result of transpiration and vice versa. The rate of evaporation doubles with every rise in temperature by 10°C. As transpiration causes cooling of leaves, the leaf

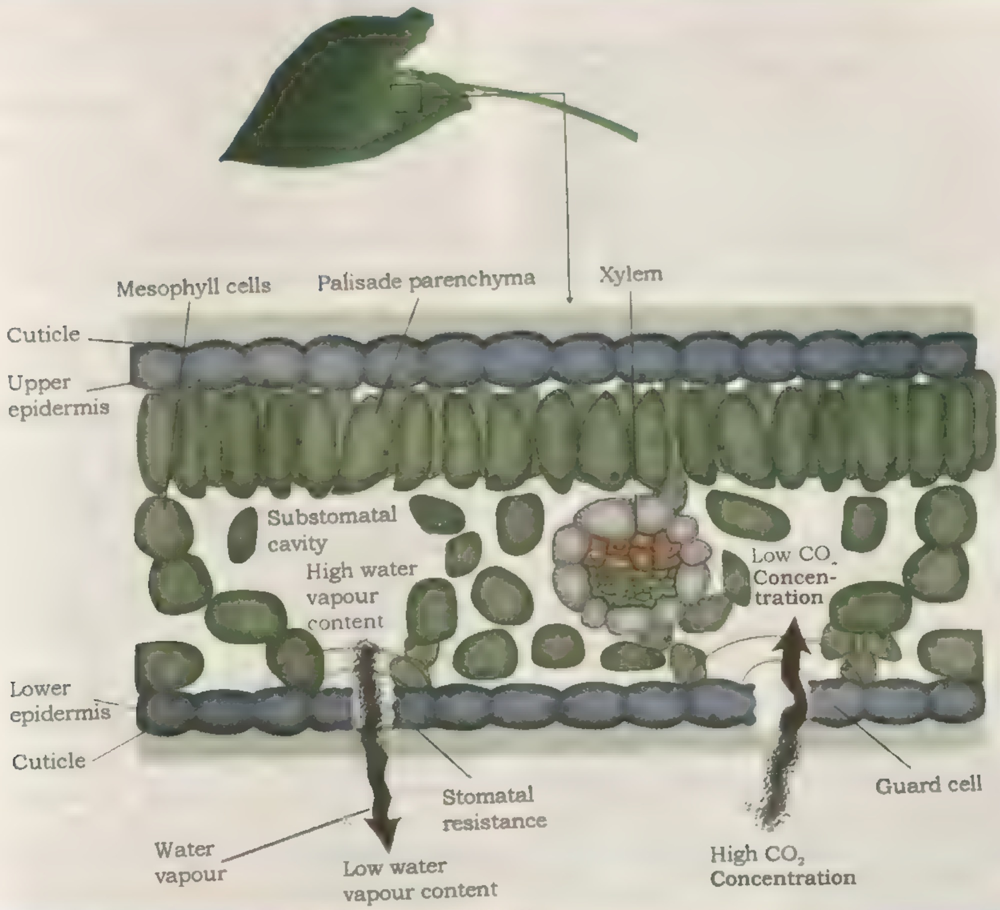


Fig. 1.6 *Water movement through the leaf to the atmosphere in the form of vapour*

temperature does not rise as much as that of the air. High temperature, influencing the closure of stomata, reduces transpiration. Wind speed also has an influence on the rate of transpiration. A high wind speed or a dry breeze will greatly increase transpiration.

Some other plant factors also affect the rate of transpiration. These factors include : efficiency of water uptake by roots, the leaf area and the leaf structure. Larger leaf area will transpire more water into the atmosphere. Leaves of plants which grow in a dry habitat develop structures like thick cuticle and sunken stomata (deep-seated) to cut down the loss of water through transpiration.

1.5 Opening and Closing of Stomata

All leaves have a large number of tiny pores, called **stomata**. These stomata are located on the surface of the epidermal layer of leaves. Each stoma is composed of two special types of epidermal cells, called **guard cells**. The guard cells control the opening and closing of stomata, which, in turn, regulate the loss of water from the leaves to the atmosphere through transpiration. The size of a typical stomatal pore ranges from 3-12 μm in width and from 10-14 μm in length. The number of such tiny pores varies from 1,000 to 60,000 per cm^2 of the leaf surface. Stomata are found on the lower (abaxial) as well as upper (adaxial)

Table 1.1 : Number of Stomata on the Upper and Lower Surfaces of Leaves

Plant	Number of Stomata/mm²	
	Upper Surface	*Lower Surface*
Monocot		
Wheat	50	40
Barley	70	85
Onion	175	175
Dicot		
Sunflower	120	175
Alfalfa	169	188
Geranium	29	179

surfaces of the leaf. However, the number of stomata on the upper and the lower surfaces of leaves varies among species (Table 1.1). In

Fig. 1.7 *Role of potassium, chloride and malate ions in stomatal opening. The ions accumulate in the vacuole of guard cells, lowering the water potential and thereby increasing water uptake and subsequently opening the stomata. (PEPcase = Phosphoenol pyruvate carboxylase)*

monocot leaves (grasses), the stomatal density or number is almost the same on both the surfaces. Leaves of dicot plants usually contain fewer stomata on the upper surface.

Opening and closing of stomata is controlled by accumulation of solutes in the guard cells. Solutes are taken in by the guard cells from the neighbouring epidermal and mesophyll cells. As a result, both osmotic potential and water potential of the guard cells are lowered. This would create a water potential gradient between the guard cells and the neighbouring cells, and will make the water move into the guard cells. The guard cells become **turgid,** and swell in size, resulting in stomatal opening. With a decline in guard cell solutes, water moves out of the guard cells, making them **flaccid**. As a result, the stomata close. Thus, the opening and closing of stomata is controlled by osmotic movement of water in or out of the guard cells along a water potential gradient.

The major solute, which is taken in by the guard cells from the neighbouring cells, is potassium. The rise in potassium levels causes stomatal opening and its decrease stimulates stomatal closing. The uptake of potassium controls the gradient in the water potential. This, in turn, triggers osmotic flow of water into the guard cells raising the turgor pressure. Role of K^+ in stomatal opening is now universally accepted. The extent of K^+ accumulation in guard cells determines the size of the stomatal opening.

The accumulation of large amounts of potassium (K^+) in guard cells is electrically balanced by the uptake of negatively charged ions – chloride and malate (Fig. 1.7). The high amount of malate in guard cells of open stomata accumulates by hydrolysis of starch.

Factors affecting Stomatal Movement

Many environmental factors affect stomatal movement. Most prominent factors include light, temperature, water availability to plants and CO_2 concentration. Some endogenous factors, like K^+, Cl^- and H^- ions and organic acids, also influence stomatal movement.

Light : Stomata open in the presence of light and close in darkness. Light intensity

required to open the stomata is very low, as compared to the intensity required for photosynthesis. Even moonlight is sufficient to keep the stomata open in some plant species. In plants with Crassulacean Acid Metabolism (CAM), stomata open during dark and remain closed during the day (see Chapter 3). This unique behaviour of stomata is a kind of adaptation to conserve moisture in CAM plants, for example, pineapple, agave, etc.

Temperature : Stomata tend to open more with an increase in temperature and close with a decrease in temperature. In some plant species, stomata remain closed even under continuous light at 0°C. However, if the temperature is increased, stomatal opening in these species increases. At temperatures higher than 30°C, there is a decline in stomatal opening in some species.

Water availability : If the water available to plants is less and transpiration rate is high, plants undergo **water stress**. Water stress (also called **water deficit** or **moisture deficit**) induces stomatal closure. This happens to conserve moisture by plants by cutting down the transpirational loss of water.

CO_2 concentration : With an increase in carbon dioxide concentration inside the leaf, the stomata close. This happens even under the light. In some plant species, stomata also close if we merely breath on their leaves. It is the internal leaf carbon dioxide concentration rather than the atmospheric carbon dioxide that dictates stomatal opening. If plants are transferred to carbon dioxide-free environment, but kept in darkness, the stomata will still remain closed. This means that, since the internal carbon dioxide is not utilised due to absence of photosynthesis in the dark, it influences the stomata to remain closed. However, if these plants are exposed to light, photosynthesis will utilise internal CO_2, permitting the stomata to open.

SUMMARY

Water is extremely essential for plant growth and development. It is absorbed by the root hairs from soil and translocated to the leaves. Various mechanisms operate for the water to move from one cell to another and, therefore, from root to stem to leaf to the atmosphere. The movement of water in the roots is through apoplast pathway and symplast pathway. However, major portion of water in the root flows via the apoplast.

Different theories have been put forth for explaining water translocation within a plant. The three most important theories are root pressure, capillarity and Cohesion Theory. Most of the water taken up by plants is lost to the atmosphere by transpiration, which occurs through tiny pores called stomata, located on the leaf surface. Only a fraction of water absorbed is utilised for the purpose of growth, maintenance and reproduction of the plants. A large number of stomata are present on the leaves, mostly on the lower leaf surface. The stomatal movements, i.e., opening and closing, control the flow of water from the plants to the atmosphere through transpiration. Transpiration helps in the movement of xylem sap, and simultaneously increases absorption of mineral nutrients by the roots from the soil. It also assists in cooling by evaporation of water and thereby reducing heat load on the leaves. Various environmental factors contribute to the occurrence of transpiration and control of stomatal movements. These factors mostly include light,

temperature, humidity, CO_2 concentration, and water availability. In addition, many endogenous factors also influence both transpiration and stomatal movements.

EXERCISES

1. Describe osmosis as a special case of diffusion.
2. Distinguish between the following :
   (a) Osmotic pressure and osmotic potential
   (b) Osmotic potential and matric potential
   (c) Diffusion and osmosis
   (d) Osmosis and imbibition
3. Describe the theories related to translocation of water.
4. In what way does the concept of water potential help in explaining water movement?
5. Of what importance is potassium in the opening and closing of stomata?
6. Is there a general mechanism to explain the opening and closing of stomata? Justify your answer.
7. Mention some of the factors that influence stomatal opening and closing. How are these factors involved in regulating stomatal behaviour?
8. Does transpiration serve any useful function in the plant?
9. Write short notes on
   (a) Plasmolysis
   (c) Imbibition
   (b) Osmosis
   (d) Root pressure
10. Describe the role of osmotic potential in regulating water potential of plant cells.

Chapter 2

PLANT NUTRITION

The basic needs of all living organisms are essentially the same, and they require macromolecules, like carbohydrates, proteins and fats, and minerals for their growth and development. Green plants can prepare most of their food from simple substances, mostly water and carbon dioxide, through the process of photosynthesis. Such organisms, which can prepare their own food through photosynthesis, are called **autotrophs**. Some other organisms, including non-green plants, which cannot make their own food and obtain their nutrition from autotrophs, are termed **heterotrophs**.

In the formation of carbohydrates, fats and proteins, carbon, hydrogen and oxygen play an important role. In addition to these three elements, plants need a variety of elements for their survival. These are generally grouped under the class, mineral elements. The source of these elements is primarily the inorganic form of ions present in the soil. These are absorbed by the root system.

The study of how plants obtain mineral elements, either through water, air or soil, and utilise them for their growth and development, is called **mineral nutrition**.

You will study about autotrophic type of nutrition in Chapter 3. In this chapter, the focus will be mainly on mineral nutrition, which includes the study of essential elements and their role, and mechanism of their absorption. In addition, the metabolism of nitrogen will be discussed in details. You will also study in brief about the heterotrophic mode of nutrition.

2.1 ESSENTIAL MINERAL ELEMENTS

An **essential element** is defined as one without which the plant cannot complete its life cycle, or one that has a clear physiological role.

The criteria for essentiality of an element are given below :

(i) The element must be absolutely necessary for supporting normal growth and reproduction.

(ii) The requirement of the element must be specific and not replaceable by another element.

(iii) The element must be directly involved in the metabolism of the plant.

Among the mineral elements absorbed by the plants, not all are essential. Out of 112 elements including synthetic ones discovered so far, only 20 have been found to be essential for plant growth and metabolism. These essential elements are divided into two broad categories, based on the quantity in which they are required by plants :

(i) macronutrients, and

(ii) micronutrients.

Macronutrients must generally be present in plant tissues in concentrations of 1 to 10 mg per gram of dry matter. The macronutrients include carbon, hydrogen, oxygen, nitrogen, phosphorous, sulphur, potassium, calcium, magnesium and silicon.

Micronutrients, or trace elements, are needed in very small amounts (equal to or less than 0.1 mg per gram of dry matter). These include-iron, manganese, copper, molybdenum, zinc, boron and chlorine. Recent research has shown that some elements, such

as cobalt, vanadium and nickel, may be essential for certain plants.

2.2 Sources of Essential Elements for Plants

The main sources of elements are soil and atmosphere. Carbon enters a plant as atmospheric carbon dioxide (see Chapter 3). Hydrogen is obtained mainly from water. Oxygen can come from the air, or from water, and in the form of inorganic ions. Carbon, hydrogen and oxygen are not minerals as they are not absorbed from the soil. But they are the building blocks of macromolecules, which make the main bulk of the plant body.

Nitrogen is not considered a true mineral. It occurs in abundance in the atmosphere. It is inert and plants cannot make use of it directly. It is absorbed by plants in the form of nitrate from the soil, that is why it is sometimes kept under the category of minerals. The other elements are absorbed from the soil, such as phosphorus as phosphate, and sulphur mainly as sulphate.

2.3 Role of Macro- and Micro-Nutrients

The essential elements perform several roles. The most important role of the elements is to participate in various metabolic activities of the plant through their effect on enzymes. Some elements regulate the permeability of cell membranes, some are required for the maintenance of osmotic pressure of cell sap, and others participate in an electron transport system, buffer action, electrical neutrality, etc. The role and symptoms of their deficiency in plants are discussed below.

The role of individual elements has been largely determined by growing plants with their roots immersed in nutrient solution without soil. This technique is known as **hydroponics**. Usually, a large volume of nutrient solution is required for hydroponic culture, and the concentration of nutrients is adjusted frequently to prevent changes in nutrient concentration and pH of the medium. Vigorous bubbling of the air through the medium is also routinely done to provide sufficient oxygen to the root system. For studying deficiency symptoms, the particular ion is eliminated from the nutrient medium. Hydroponics, or water culture, has found wide application in growing many crops under artificial conditions for economic purposes as well.

You already know that carbon, hydrogen and oxygen are the building blocks of macromolecules. Now, you will study about other elements.

Nitrogen : This is the mineral element required by plants in greatest amount. It is absorbed as NO_2^-, NO_3^- or NH_4^+. This is required by all parts of a plant, particularly the meristematic tissues. Nitrogen is one of the major constituents of proteins, nucleic acids, vitamins and hormones. Its deficiency causes yellowing of older leaves (chlorosis), stunting of plants, dormancy of lateral buds, late flowering, purple colouration in shoot axis surface, wrinkling of cereal grains, and inhibition of cell division.

Phosphorus : Phosphorus is absorbed by the plants from soil in the form of phosphate ions (either as $H_2PO_4^-$ or HPO_4^{2-}). Phosphorus is a constituent of cell membrane, certain proteins, all nucleic acids and is required for all phosphorylation reactions. Deficiency of phosphorus causes delay in seed germination, purple or red spots on leaves, dark green leaves, premature fall of leaf and flowerbuds.

Potassium : It is absorbed as potassium ion (K^+). In plants, this is more abundant in meristematic tissues, buds, leaves and root tips. Potassium helps determine anion-cation balance in cells and is involved in protein synthesis, opening and closing of stomata, activation of enzymes and maintenance of turgidity of cells. Its deficiency induces scorched leaf tips, shorter internodes, dieback, chlorosis in inter-veinal areas, loss of apical dominance, bushy habit, loss of cambial activity, plastid disintegration and increase in rate of respiration.

Calcium : Plant absorbs calcium from the soil in the form of calcium ions (Ca^{2+}). Calcium is required by meristematic and differentiating

tissues. Calcium is also used in the mitotic spindle during cell division. It accumulates in older leaves. It is involved in the normal functioning of cell membranes. It activates certain enzymes and plays an important role in regulating metabolic activities. It is used in the synthesis of cell wall, particularly as calcium pectate in the middle lamella. The deficiency of calcium leads to stunted growth, necrosis of young meristematic regions, such as root tips or young leaves.

Magnesium : It is absorbed by the plants in the form of divalent Mg^{2+}. It activates enzymes in respiration and photosynthesis, and in the synthesis of DNA and RNA. Magnesium is a constituent of the ring structure of chlorophyll and maintains ribosome structure. Deficiency of magnesium induces chlorosis between the leaf veins (interveinal chlorosis) and necrotic or purple coloured spots on older leaves. Magnesium deficiency may cause premature leaf abscission.

Sulphur : Plants obtain sulphur in the form of sulphate (SO_4^{2-}). Sulphur is present in two amino acids, cysteine and methionine, and is the main constituent of several coenzymes, vitamins (thiamine; biotin; CoA) and ferredoxin. Sulphur deficiency causes chlorosis of younger leaves, stunted growth and anthocyanin accumulation. These symptoms are essentially similar to those of nitrogen deficiency because sulphur and nitrogen are constituents of proteins.

Iron : Plants obtain iron in the form of ferric ions (Fe^{3+}). It is required in larger amounts in comparison to other micronutrients. It is an important constituent of proteins like ferredoxin and cytochromes, involved in transfer of electrons. It is reversibly oxidised from Fe^{2+} to Fe^{3+} during electron transfer. It activates catalase, and is essential for the formation of chlorophyll. The chlorosis of leaves is a typical symptom of iron deficiency. Initially, the intravenous regions of the leaves become chlorotic and on prolonged deficiency, veins also become chlorotic

Manganese : It is absorbed in the form of manganous cation (Mn^{2+}). It activates many enzymes involved in photosynthesis, respiration and nitrogen metabolism. The best defined function of manganese is in the splitting of water to liberate oxygen during photosynthesis. Plants deficient in manganese show chlorosis and grey spots on leaves.

Zinc : Plants obtain zinc as (Zn^{2+}) ion. It activates various enzymes, especially carboxylases. It is needed in the synthesis of auxin. The deficiency symptoms of zinc are malformed leaves, inter-veinal chlorosis in leaves, and stunted growth.

Copper : It is absorbed as cupric ion (Cu^{2+}). It is essential for the overall metabolism in plants. Like iron, it is associated with certain enzymes involved in redox reactions and is reversibly oxidised from Cu^{+} to Cu^{2+}. Plants deficient in copper show necrosis of the tip of young leaves, which extend towards the leaf base along the margins. In fruit trees, it causes dieback of shoot, where leaves wither and fall and bark becomes rough and splits, exuding gummy substances.

Boron : It is absorbed as BO_3^{3-} or $B_4O_7^{2-}$. Boron is required for uptake and utilisation of Ca^{2+}, membrane function, pollen germination, cell elongation, cell differentiation, and carbohydrate translocation. The symptoms of boron deficiency include death of root and shoot tips, loss of apical dominance, abscission of flowers, small size of fruits, absence of root nodules in leguminous plants, and stunted growth.

Molybdenum : Plants obtain it in the form of molybdate ion (MoO_2^{2+}). It is a component of several enzymes, including nitrogenase and nitrate reductase, which participate in nitrogen metabolism. Molybdenum deficiency may cause nitrogen deficiency, as it is a component of enzymes involved in nitrogen metabolism. Plants deficient in molybdenum show slight retardation of growth, inter-veinal chlorosis, etc.

Chlorine : It is absorbed in the form of chloride anion (Cl^{-}). With Na^{+} and K^{+}, it helps in determining solute concentration and anion-cation balance in cells. Chlorine may be required for cell division in both leaves and roots. It is essential for water-splitting reaction in photosynthesis, which leads to oxygen evolution. The plants deficient in chlorine show wilted leaves, stunted root growth, and reduced fruiting.

2.4 Mechanism of Absorption of Nutrients

Studies on uptake of mineral ions by single plant cells, isolated tissues and organs, show that two main phases are involved in this process. In the first phase, tissues kept in mineral solutions show an initial rapid uptake of ions into the 'free space' or 'outer space' of the cells. In the second phase of uptake, ions are taken in slowly into the 'inner space' of cells. The ions exist in a freely exchangeable form is shown by the fact that labelled ions, for example, labelled K^+ can be 'chased' out by normal (unlabelled) K^+. In the inner space of the cell, the ions are not in a freely exchangeable form. The outer space includes the intercellular space and cell wall, and the inner space refers to most of the cytoplasm and the vacuole. Entry of ions into the outer space seems to be passive (i.e. does not require expenditure of metabolic energy), whereas entry into and/or exit from the inner space, usually requires metabolic energy and is, therefore, an active process. The movement of ions is usually termed as **flux**. The movement into the cell is **influx** and the outward movement is **efflux**.

Passive Absorption

Passive absorption is the absorption of minerals by physical processes not involving direct expenditure of metabolic energy.

As mentioned in connection with water absorption, a substance moves passively from its region of higher concentration to a region of lower concentration. According to newer concepts based on free energy, a substance moves from a region of its higher chemical potential to a region of lower chemical potential (along the chemical potential gradient). Chemical potential is the mole fraction contribution of a substance to the total free energy of the system, and it is related only to the concentration of substance. With electrolytes, i.e. ions, there is an additional factor, the charge of the ions. Thus, while non-electrolytes have chemical potential, the electrolytes have the electrochemical potential (ecp). An ion, therefore, moves passively from a region of its higher electrochemical potential to that of lower electrochemical potential. The passive movement of ions usually occurs through ion channels. The **ion channels** are trans-membrane proteins that function as selective pores.

Ions can also be absorbed and accumulated against an ecp gradient without the use of metabolic energy. Several theories/hypotheses have been proposed to explain the movement of ions against an ecp gradient, such as ion exchange, Donnan equilibrium, and mass flow of ions.

Ion exchange : Ions, both cations and anions, have a tendency to get adsorbed on the surfaces of the cell walls, and exchange with ions of the same charge present in the soil solution. The process of exchange between adsorbed ions and ions in solution is known as **ion exchange**. This is illustrated in Figure 2.1.

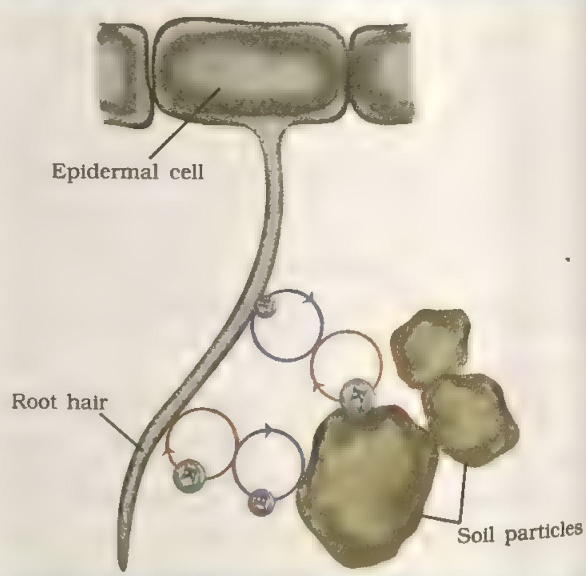


Fig. 2.1 *Contact exchange theory*

Donnan equilibrium : This theory explains the passive accumulation of ions that are fixed or non-diffusible, against an ecp gradient. For example, there is a membrane that separates a cell from the external medium and allows exchange of some ions and not others. To the inner side of this membrane,

there are anions, which are fixed and non-diffusible and, therefore, the membrane becomes impermeable to these anions. In such a situation, for equilibrium to be reached, additional (mobile) cations are needed to balance the negative charges of the anions that are structurally bound to the inner side of the above membrane. According to this theory, Donnan equilibrium is attained if the product of anions and cations in the internal solution becomes equal to the product of anions and cations in the external solution, as given below :

$$[Ci^+][Ai^-] = [Co^+][Ao^-], \text{ where}$$

Ci^+ = cations inside; Co^+ = cations outside;
Ai^- = anions inside; Ao^- = anions outside

Mass flow hypothesis **:** According to this hypothesis, roots also absorb a large quantity of ions along with the absorption of water, due to transpiration. An increase in water flow in the plant due to transpirational pull also increases the total uptake of ions by roots. This occurs due to passive absorption of ions by free diffusion into the apparent free space of a tissue. Thus, mass flow of ions through root tissue occurs as a result of transpirational pull in the absence of metabolic energy.

Active Absorption

Ions are known to accumulate in cells, i.e. they may move (e.g., into the inner space) against concentration or ecp gradients. This movement requires additional energy. The additional energy is derived directly, or indirectly, through metabolism. Various evidences indicate that active ion uptake is probably carried out by carrier mechanism for both the influx and efflux of ions, and have indicated the existence of ionic pumps (Fig. 2.2). There has been a lot of speculation on the possible nature of the carriers.

Unlike ion channels, the carrier proteins do not have pores. In the carrier mechanism, activated ions combine with carrier proteins and form ion-carrier complex. This complex moves across the membrane and reaches the inner surface. Here, the complex breaks and releases ions into the cytoplasm of the cell.

Ion Traffic into the Root

Mineral nutrients absorbed by the root are carried to the xylem. This takes place by two pathways – apoplast and symplast (Fig. 2.3).

The apoplastic pathway, essentially, involves diffusion and bulk flow of water from cell to cell through spaces between cell wall polysaccharides. The ions entering the cell wall of epidermis move across cell wall of cortex, cytoplasm of endodermis, cell walls of pericycle, and finally, accumulate in xylem vessels.

In symplast pathway, ions entering the cytoplasm of epidermis move across the cytoplasm

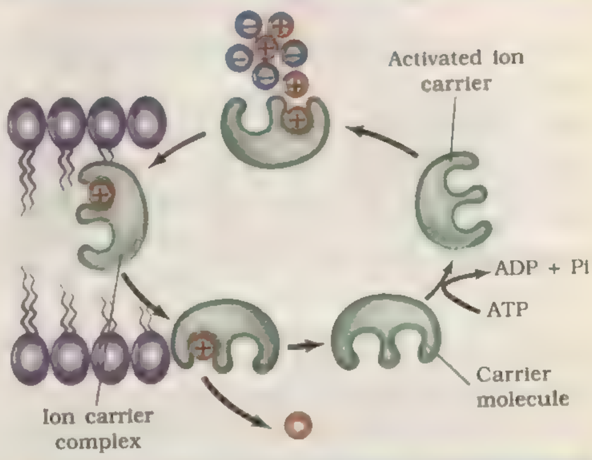


Fig. 2.2 *Carrier concept*

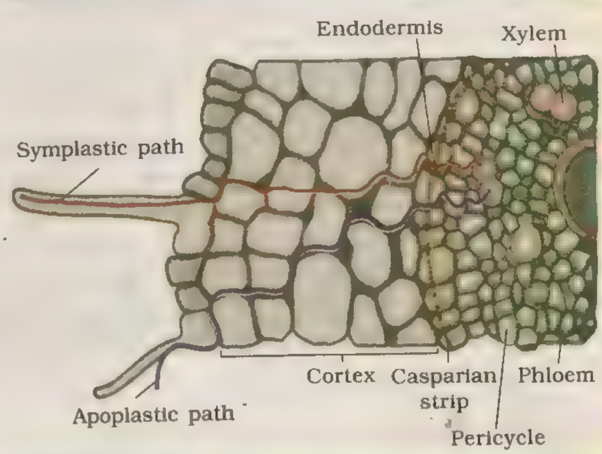


Fig. 2.3 *Anatomical aspects of symplastic and apoplastic pathways of ion absorption in the root-hair region*

of cortex, endodermis and pericycle through plasmodesmata, and finally, to xylem vessels.

2.5 Translocation of Solutes

P.R. Stout and D.R. Hoagland (1939) proved that mineral salts are translocated through xylem. Any solute conducted through the xylem is carried along with the ascending streams of water, which are pulled up through the plant by transpirational pull. The rates at which inorganic solutes are translocated through the xylem vessels, correspond closely with the rates of translocation of water. Analysis of xylem sap shows the presence of inorganic salts. By feeding plants with radioisotopes, it was shown conclusively that inorganic substances move up the plant through xylem.

2.6 Metabolism of Nitrogen

Nitrogen Cycle

With the exception of carbon, hydrogen and oxygen, nitrogen is the most prevalent element in the living organisms. This is found in such essential compounds as proteins, nucleic acids, growth regulators and many of the vitamins. One of the fundamental biological requirements for life to persist is that the nitrogen cycle should continue to function. During this process, the atmospheric nitrogen is fixed into organic combinations, such as amino acids, proteins, nucleic acids, etc., in living organisms via inorganic forms such as NH_4^+. As living organisms die and decay, inorganic nitrogen is liberated. The dead remains of animals and plants are decomposed through microbial activities to produce ammonia **(ammonification)**. This ammonia is rapidly converted first to nitrites, and then to nitrates, by the process of ***nitrification***. The conversion of ammonia to nitrite is carried out by the bacteria, *Nitrosomonas*, and that of nitrite to nitrate by *Nitrobacter*.

$$2NH_3 + 3O_2 \longrightarrow 2NO_2^- + 2H^+ + 2H_2O$$
$$2NO_2^- + O_2 \longrightarrow 2NO_3^-$$

Nitrate is then either available to the plant, or converted to nitrogen gas in the process of **denitrification** by other micro-organisms, e.g. *Pseudomonas*. The nitrogen gas may be again fixed in the form of NH_4^+ through the process of biological nitrogen fixation.

Biological Nitrogen Fixation

Biological nitrogen fixation is carried out by both free-living and symbiotic bacteria. The free-living nitrogen fixers include cyanobacteria, *Azotobacter* and *Clostridium*.

Some higher plants possess an ability to take up atmospheric N_2 through a process, called **symbiotic N_2 fixation**. This sort of N_2 fixation, in addition to the nitrogen available from the soil, occurs only in leguminous plants (for example chickpea, *Cicer arietenum*) in association with a bacterium, called *Rhizobium*. The association of plants and the *Rhizobium* is of symbiotic nature; the process of N_2 fixation carried out is, thus, called symbiotic N_2 fixation. This bacterium lives in the soil to form root nodules in plants of family Fabaceae (leguminous plants), which is most effective for nodule formation. Nodules are little outgrowths on the roots.

Nodule acts as a site for N_2 fixation. It contains all the necessary biochemical components, such as the enzyme nitrogenase and leghaemoglobin. The enzyme nitrogenase is a Mo-Fe protein and catalyses the conversion of atmospheric N_2 to NH_3 as given in the equation below :

$$N_2 + 8e^- + 8H^+ + 16ATP \longrightarrow 2NH_3 + H_2 + 16ADP + 16\ Pi$$

This enzyme is extremely sensitive to oxygen. To protect it from oxygen, nodules contain an oxygen scavenger, called **leghaemoglobin (Lb)**, which is pink in colour and similar to haemoglobin of vertebrates.

How are these root nodules formed? When a root hair of a leguminous plant comes in contact with *Rhizobium*, it curls or is deformed. Specific chemical substances secreted by the bacteria are responsible for the curling. At the site of curling or deformation of root hair, rhizobia invade the root tissue and proliferate within the root hair. The plant responds by forming an infection thread, made up of the plasma membrane, that grows inward from the infected cell of the host, separating the infected

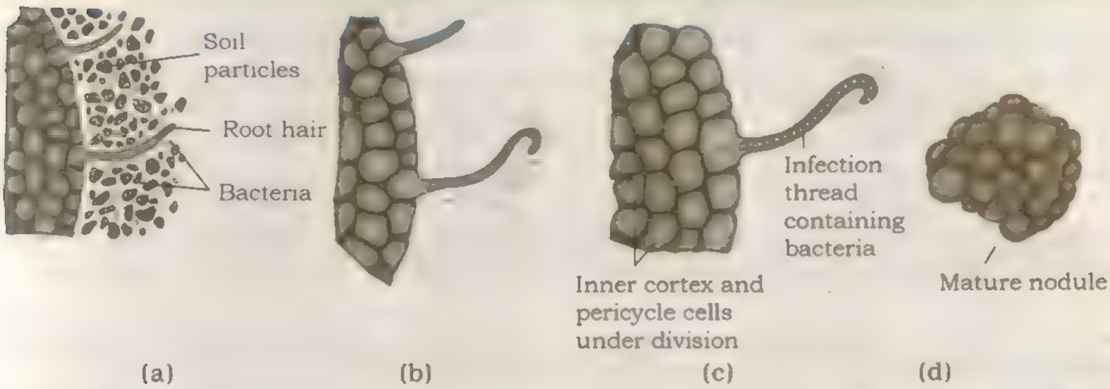


Fig. 2.4 *(a) Development of root nodules in soyabean. (b) Rhizobium bacteria contact a susceptible root hair, divide near it, and upon successful infection of the root hair cause it to curl. (c) Infection thread carrying dividing bacteria, now modified and apparent as bacteroids. Bacteroids cause inner cortical and pericycle cells to divide. Division and growth of cortical and pericycle cells lead to nodule formation. (d) A mature nodule complete with vascular tissues continuous with those of the root*

tissue from the rest of the plant. Cell division is stimulated in the infected tissue and more bacteria invade the newly formed tissues. It is believed that a combination of cytokinin produced by the invading bacteria and auxin produced by plant cells, promotes cell division and extension, leading to nodule formation. Some of the bacteria enlarge to become membrane-bound structures called **bacteroids**. Different steps of nodule formation are shown in Figure 2.4. The nodule thus formed, establishes a direct vascular connection with the host for the exchange of nutrients.

However, at this point, it is pertinent to make a mention that nitrogen fixation, as such, occurs under the control of plant *nod* genes and bacterial *nod*, *nif* and *fix* gene cluster.

During this process, the atmospheric N_2 is reduced by the addition of hydrogen atoms.

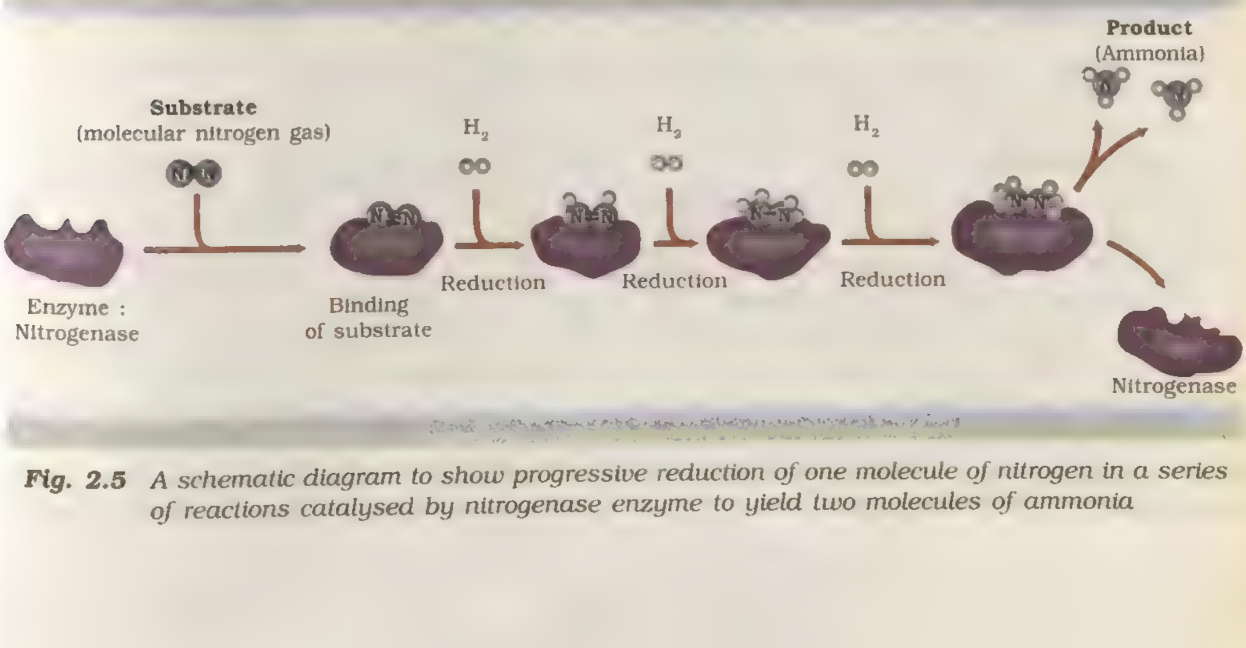


Fig. 2.5 *A schematic diagram to show progressive reduction of one molecule of nitrogen in a series of reactions catalysed by nitrogenase enzyme to yield two molecules of ammonia*

The three bonds between the two nitrogen atoms (N≡N) are broken and ammonia is formed (Fig. 2.5). Nitrogen fixation requires three components :

(i) a strong reducing agent,
(ii) ATP to transfer hydrogen atoms to dinitrogen, and
(iii) the enzyme systems.

The reducing agent (FAD) and ATP are provided by photosynthesis and respiration.

Ammonia, so formed, is used for the synthesis of amino acids. Amino acids are translocated to other parts of the plant, which act as building blocks for the synthesis of various types of proteins.

Synthesis of Amino Acids

Amino acids are generally the initial products of nitrogen assimilation. Each amino acid consists of at least one carboxyl (–COOH) group and one or several amino ($-NH_2$) groups. There are two main processes by which majority of amino acids in plants are synthesised.

(i) ***Reductive amination*** : In this process, ammonia reacts with α-ketoglutaric acid and forms glutamic acid as indicated below :

$$\alpha\text{-ketoglutaric acid} + NH_4^+ + NAD(P)H \xrightarrow[\text{dehydrogenase}]{\text{Glutamate}} \text{Glutamate} + H_2O + NAD(P)$$

(ii) ***Transamination*** : It involves the transfer of amino group from one amino acid to the keto group of keto acid. Glutamic acid is the main amino acid from which other 17 amino acids are formed through transamination. The enzyme responsible for such reaction is termed as **transaminase**.

Amides : The two most important amides found in plants are asparagine and glutamine. These are formed from two amino acids, namely glutamic acid and aspartic acid. In this process, hydroxyl part of the acid is replaced by another NH_2 radical. The reaction takes place in the presence of the enzymes glutamine synthetase or asparagine synthetase. Amides contain more nitrogen than amino acids and are structural part of most proteins.

Protein Synthesis

Proteins consist of one or more chains called **polypeptide chains**, each of which consists of hundreds of amino acids. The number of amino acids varies greatly among proteins and therefore, the molecular weight of proteins also varies. The linkage of amino acids and amides in the polypeptide chain occurs through **peptide bond**, involving the carboxyl group of one amino acid and the amino group of the next. The proteins are highly specific due to the sequence in which the amino acids are present in the protein.

2.7 Heterotrophic Nutrition

As you know, the non-green plants, such as some phanerogams, fungi and bacteria, are heterotrophic and cannot prepare their own food. Heterotrophic plants could be **parasitic**, **saprophytic**, **symbionts** and **insectivorous**.

(i) The plants that obtain all or part of their food from living tissues of another plant (host), with which they maintain physical contact, are called parasites. Parasitic phanerogams develop haustoria, which penetrate into the vascular bundles of the host plant. Thus, the water and solutes are absorbed by the parasites.
(ii) Saprophytic plants, such as Monotropa, bacteria and fungi, grow on decaying animal or vegetable matter and absorb the organic food from it.
(iii) Two organisms that live in close physical association, and are of mutual benefit to each other, are called symbionts. This condition is known as symbiosis. Lichen, mycorrhiza, etc. are examples of symbionts.
(iv) There are some green plants, which obtain their nourishment partly from the soil and atmosphere, and partly by catching and digesting small insects. These plants possess specialised leaves to trap insects. The trapped insects are killed and their proteins are digested by proteolytic enzymes secreted by the epidermis of the leaf. The amino acids are then absorbed by the plant, thus, supplementing its nitrogen supply. These plants are called *insectivorous plants*.

SUMMARY

There are three sources that supply inorganic nutrients to plants. These sources are soil, air and water. Plants absorb a wide range of mineral elements. Out of 112 elements including synthetic ones only 20 elements are essential for the normal growth and metabolism of plants. There are some elements which are required in large quantities (macro-nutrients) by the plants, whereas others in less amount (micro-nutrients). These elements become the essential constituents of protein, carbohydrate, fat, nucleic acid, etc. and take part in various metabolic processes. Some of them serve as activators/co-factors for several enzymes. Deficiency of any element in plants may lead to symptoms such as chlorosis, necrosis, stunted growth, etc. Plants absorb mineral elements through root by passive or active absorption. The absorbed elements are then transported from the root to the xylem by apoplastic and symplastic pathways.

Nitrogen is very essential for sustenance of life. Plants cannot use atmospheric nitrogen directly. It is, therefore, necessary that atmospheric nitrogen is fixed into organic combination. Nitrogen fixation requires a strong reducing agent, energy in the form of ATP, and the enzyme systems. This task is accomplished by certain nitrogen fixing bacteria and cyanobacteria. *Rhizobium* is associated symbiotically with the roots of leguminous plants. These bacteria form nodules in the roots. The atmospheric nitrogen is fixed in the form of NH_4^+ through the process of nitrogen fixation.

Ammonia is usually converted to nitrates. Plants can absorb nitrates which are again converted to ammonia by enzymatic reactions. Ammonium ions are then used for the synthesis of amino acids and proteins and other nitrogenous compounds in the plant.

EXERCISES

1. Define the following :
   (a) Nutrients
   (b) Nutrition
   (c) Micronutrients
   (d) Macronutrients
   (e) Active absorption
   (f) Passive absorption
   (g) Symplastic pathway
   (h) Apoplastic pathway
2. Give three criteria of essentiality of an element.
3. Write an explanatory note on biological nitrogen fixation.
4. Make a list of macronutrients and mention their major functions.
5. Write short notes on :
   (a) Reductive amination, and
   (b) Transamination.
6. What do you understand by heterotrophic mode of nutrition? Elaborate your answer with suitable examples.

Chapter 3

Photosynthesis

In Class XI, you have read about the structure of chloroplast. In this chapter, you will learn about the function of chloroplasts in detail, that is, photosynthesis. The chapter covers, in addition to a brief historical perspective, description of photochemical and biosynthetic phases, photorespiration, C_4 pathway, factors affecting photosynthesis, translocation of photosynthates, and significance of photosynthesis.

Photosynthesis, as you know, is a process by which green plants synthesise their own food in the presence of light. Plants have the ability of capturing energy coming from the sun in the form of light, and converting it to chemical energy. This chemical energy is used for the growth and sustenance of our biosphere. Photosynthesis by plants requires carbon dioxide from the atmosphere and uses light energy from the sun for converting CO_2 to complex foods, which are consumed by man and animals. It also provides energy in the form of fossil fuels derived from prehistoric photosynthetic products. Thus, photosynthesis is the single most important biological process for the biosphere.

3.1 Historical Perspective

Study on photosynthesis originated only about 300 years ago. Before this, Aristotle and other Greeks thought that plants get their food only from the soil. Later, the Belgian physician, Jan Baptista van Helmont, did a simple experiment and concluded that all the substance of the plant was produced from water and none from the soil. By the end of the eighteenth century, Joseph Priestley (1733-1804) showed that plants have the ability to take up CO_2 from the atmosphere and release O_2. Later, in 1780, the Dutch physician Jan Ingenhousz (1730-1799) confirmed Priestley's work. He further discovered that release of O_2 by plants was possible only in sunlight and only by the green parts of the plants. Shortly thereafter, a Swiss scholar, Theodore de Saussure, found that water is an essential requirement for photosynthesis to occur.

Thus, it became clear that green plants, apart from taking nutrients from soil, make their own food by utilising CO_2, water and sunlight. This became the basis of photosynthesis. During this process, O_2 is evolved and released to the atmosphere. A simplified equation of photosynthesis was given by C.B. van Niel of Stanford University, USA :

$$CO_2 + 2H_2O \xrightarrow[\text{Chlorophyll}]{\text{Light energy}} (CH_2O)_n + H_2O + O_2$$

In photosynthesis, carbon dioxide is fixed (or chemically reduced) to carbohydrate $(CH_2O)_n$, where n is an integer. In glucose, n is 6, and thus, the chemical formula of glucose is $C_6H_{12}O_6$. Water molecule is split in the presence of light (called photolysis) to release O_2. Note that O_2 released in the above equation is from H_2O and not from CO_2.

3.2 Site for Photosynthesis

Photosynthesis takes place only in the green parts of the plant, mostly in leaves, and to a lesser extent in green stems or floral parts. Within a leaf, photosynthesis occurs particularly in specialised cells, called

mesophyll cells. These cells contain the **chloroplasts**, which are the actual sites for photosynthesis in green plants. Chloroplasts are located at the outer margins with their broad surfaces parallel to the cell wall of the mesophyll cells. This helps in easy diffusion of CO_2 required for photosynthesis from the atmosphere to the inside of chloroplasts.

The thylakoids in the chloroplasts contain most of the machinery for the photochemical reactions of photosynthesis. They contain pigments required for capturing solar energy to initiate photosynthesis. The major form of pigment present in thylakoids is chlorophyll. A pigment is a substance that absorbs light of different wavelengths. Chlorophyll, however, is a pigment that gives green colour to the leaves. It absorbs light in the violet and blue wavelengths, and also in the red region of the visible spectrum of light. This portion of the spectrum between 400nm and 700nm is also referred to as **photosynthetically active radiation** (**PAR**) (Fig. 3.1). But, the chlorophylls reflect the green light, and hence, they impart green colour to the leaves.

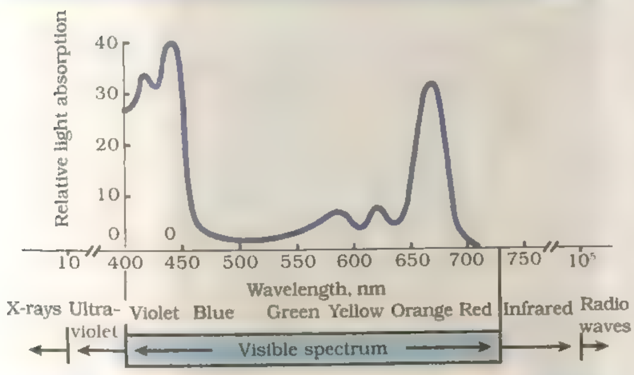


Fig. 3.1 *Absorption spectrum of chlorophyll showing maximum absorption in the blue and red regions of the visible spectum of light*

Chlorophyll is the principal pigment involved in photosynthesis. It is a large molecule composed of four 5-membered rings, called **pyrrole rings**, and a central core of magnesium. A side chain, called the **phytol chain**, extends from one of the pyrrole rings in the chlorophyll molecule (Fig. 3.2). This long side chain composed of hydro-carbons helps to anchor the chlorophyll molecules within the thylakoid membranes in the chloroplasts. There are different kinds of chlorophyll molecules present in photosynthetic organisms. In higher plants, mostly there are two kinds : chlorophyll *a* and chlorophyll *b*. Both chlorophyll *a* and *b* are very similar in their molecular structure, except that the $-CH_3$ group present in chlorophyll *a* and $-CHO$ group in chlorophyll *b*.

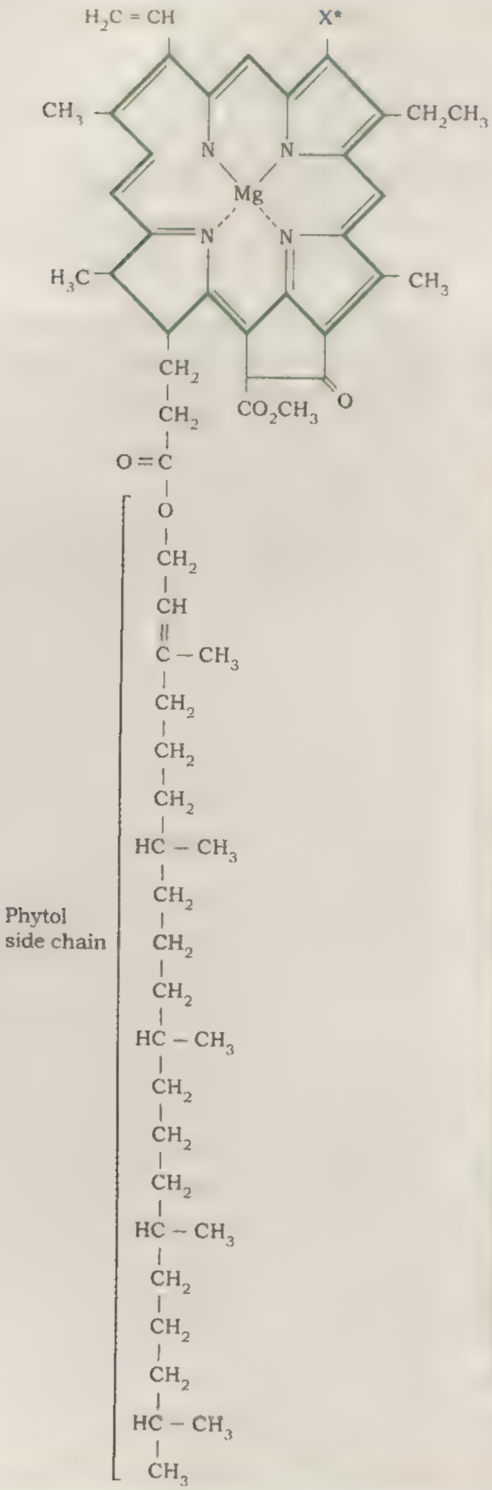
Chlorophyll *a* is the major pigment involved in trapping and converting light energy into chemical energy (Fig. 3.3). Chlorophyll *b* acts as an accessory pigment and helps absorb light form a broader spectrum during photosynthesis. Chlorophyll *b* constitutes about one-fourth of the total chlorophyll content and absorbs light of different wavelength than the chlorophyll *a*. On absorbing light, the chlorophyll *b* molecule is excited and transfers its energy to the chlorophyll *a* molecule. Thus, chlorophyll *a* molecules act as **reaction centres.**

Pigments other than chlorophyll are also involved in the process of photosynthesis. These pigments, called **carotenoids**, are of red, orange and yellow colours. Like chlorophyll they are also embedded in the thylakoid membranes of chloroplasts. These accessory pigments act as antenna complexes and harvest light from different wavelengths of the spectrum other than that of the chlorophyll. The light captured by these pigments is funnelled into the reaction centres (chlorophyll *a*) for conversion into the electrical energy (Fig. 3.4). The accessory pigments and the reaction centre, together form **photosystem.**

3.3 The Photochemical and Biosynthetic Phases

Photochemical Phase (*Light reactions*)

By now, we have learnt that different pigments – chlorophyll *a*, chlorophyll *b* – and carotenoids



Molecular Model of Chlorophyll

Fig. 3.2 *The chemical structure of chlorophyll. X*: – CH_3 in Chlorophyll a. – CHO in Chlorophyll b*

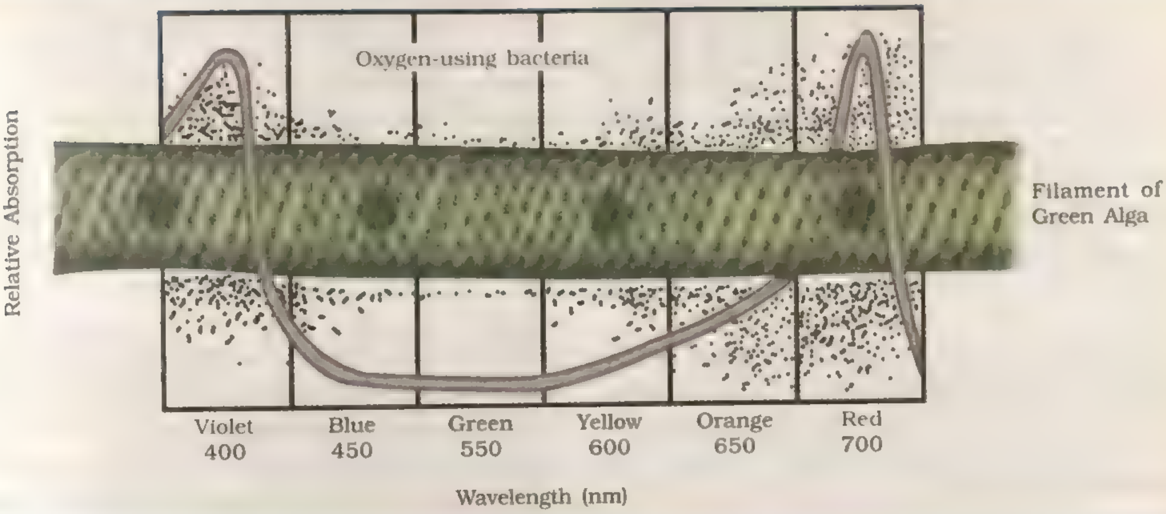


Fig. 3.3 *Action spectrum of photosynthesis determined by T.W. Englemann in 1882 using green alga. The scientist measured rate of photosynthesis as the amount of O_2 released, which he detected by using bacteria that are attracted by O_2. Note that the above action spectrum parallels the absorption spectrum of chlorophyll a, meaning thereby that photosynthesis depends on the light absorbed by chlorophyll*

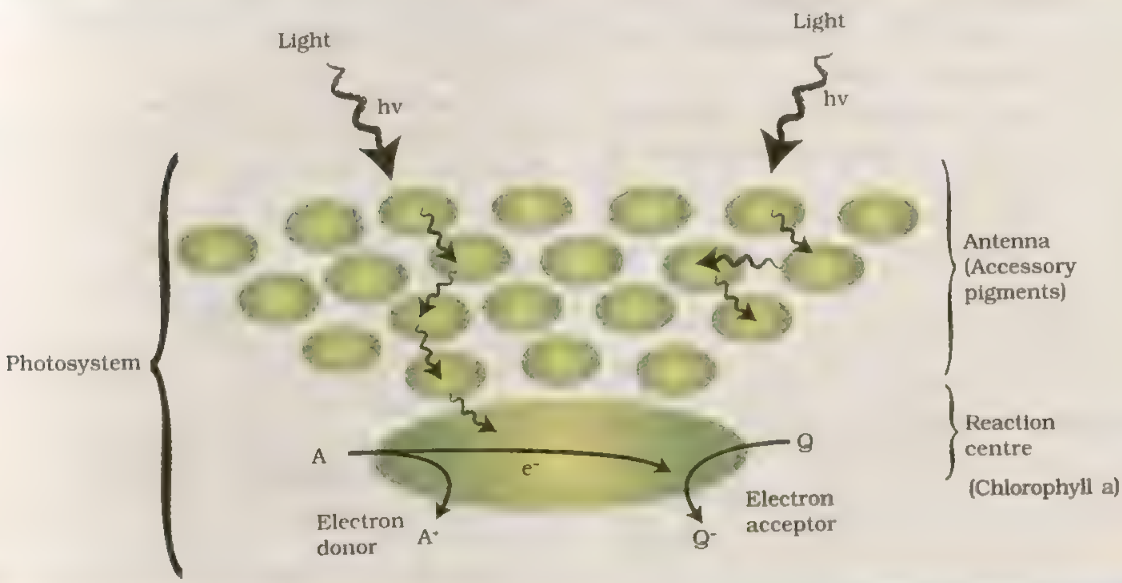


Fig. 3.4 *Conversion of light into electrical energy. Accessory pigment molecules absorb light and funnel it to the reaction centre for conversion to electrical energy*

participate in photosynthesis. Chlorophyll *a* is present in different forms, which have maximum absorption at different wavelengths of visible light. For instance, one of the forms shows an absorption peak at a wavelength of 670 nanometers (nm) and is designated as **Chl *a* 670**. Similarly, two other forms of chlorophyll *a* are **Chl *a* 680 (P_{680})** and **Chl *a* 700 (P_{700})**, with peak absorption at 680 and 700 nm, respectively. These pigments are anchored in thylakoids in discrete units of organisation called **photosystems** (Fig. 3.4). About 250 to 400 pigment molecules constitute a single photosystem. Two different photosystems exist with different forms of chlorophyll *a* as the reaction centre. In **photosystem I** (PS I), chlorophyll *a* with maximum absorption at 700 nm (P_{700}), and in **photosystem II** (PS II), chlorophyll *a* with peak absorption at 680 nm (P_{680}), acts as reaction centres. Here, *P* stands for pigments. The PS II is located in the appressed regions of grana thylakoids, and the PS I in the stroma thylakoids and non-appressed regions of grana. The primary function of the two photosystems which interact with each other, is to trap light energy and convert it to the chemical energy (ATP). This chemical energy stored in the form of ATP is used by living cells.

Electron Transport Chain

The light-driven reactions of photosynthesis, referred to as **electron transport chain**, were first formulated by Robert Hill in 1939. The electron transport chain of photosynthesis is initiated by the absorbance of light by the photosystem II (P_{680}) (Fig. 3.5). When P_{680} absorbs light, it is excited and its electrons are transferred to an electron acceptor molecule. By doing so, P_{680} becomes a strong oxidising agent and splits a molecule of water to release oxygen. This light-dependent splitting of the water molecule is called **photolysis**. Manganese, calcium and chloride ions play prominent roles in the photolysis of water. With the breakdown of water, electrons are generated, which are then passed to the oxidised P_{680}. Thus, the electron-deficient P_{680} (because it had transferred its electrons to an acceptor molecule before) is able to restore its electrons from the water molecule. After accepting electrons from the excited P_{680}, the primary electron acceptor (pheophytin in plants) is reduced. The reduced acceptor (a strong reducing agent) now donates its electrons to the downstream components of the electron transport chain.

Similar to the photosystem II (P_{680}), photosystem I (P_{700}) is excited on absorbing light and gets oxidised. It transfers its electrons to the primary electron acceptor, which, in turn, gets reduced. While the oxidised P_{700} draws electrons from photosystem II, the reduced electron acceptor of photosystem I, transfers electrons to ferredoxin and ferredoxin-NADP reductase to reduce $NADP^+$ to NADP. The $NADPH^+$, a powerful reducing agent, is then utilised in the reduction of CO_2 to carbohydrates in the carbon reaction of photosynthesis. The reduction of CO_2 to carbohydrates also requires energy in the form of ATP, produced during light reactions. This process of ATP formation from ADP in the presence of light in chloroplasts is called **photophosphorylation**.

Photophosphorylation

Photophosphorylation occurs in chloroplasts in two ways :

(i) Non-cyclic, and
(ii) Cyclic.

Non-cyclic photophosphorylation : Non-cyclic photophosphorylation is a result of an interaction of photosystem I and photosystem II. As discussed above, there is a continuous flow of electrons from water to photosystem II to photosystem I, and finally, to NADP. As the electrons pass downhill in an electron transport chain, ATP is formed from ADP (Fig. 3.5). Because the electron flow from water to NADP is unidirectional, the process of ATP formation is termed as non-cyclic photophosphorylation.

Cyclic photophosphorylation : When non-cyclic photophosphorylation is stopped under certain conditions, cyclic photophosphorylation occurs. The non-cyclic photophosphorylation can be stopped by illuminating isolated chloroplasts with light of wavelengths greater than 680nm. By this way, only photosystem I is activated, as it has a

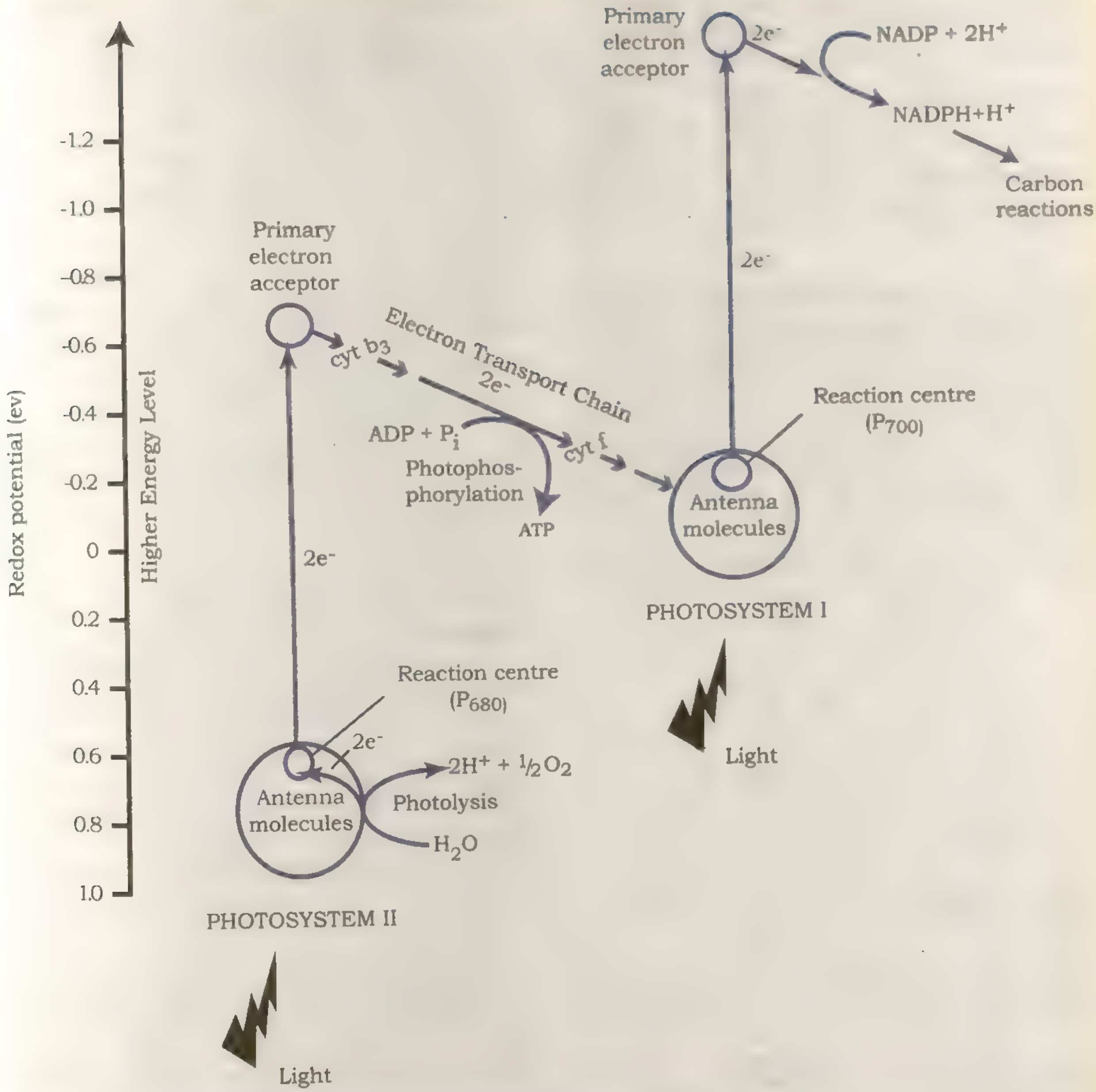


Fig. 3.5 *Electron transport flow and non-cyclic photophosphorylation : Light energy absorbed by the reaction centre, P_{680} of Photosystem II is used in taking electrons to a higher energy level, which are then replaced by electrons drawn from water molecules. The electrons enter electron transport chain and are passed to a lower energy level, that is, the reaction centre, P_{700} of Photosystem I. During this process, energy is released and stored in the form of ATP. From Photosystem I, the electrons are passed to another primary electron acceptor and via other electron carriers to $NADP^+$ to form NADPH. ATP and $NADPH+H^+$ thus formed are used in carbon reactions to fix CO_2 to $(CH_2O)_n$*

maximum absorption at 700nm, and photosystem II, which absorbs at 680nm, remains inactivated. Due to the inactivation of photosystem II, the electron flow from water to $NADP^+$ is stopped, and also CO_2 fixation is retarded. When CO_2 fixation is stopped, electrons will not be removed from the reduced NADPH. This means that NADPH will not be oxidised and $NADP^+$ will no longer be available as an electron acceptor. Under these circumstances, cyclic photophosphorylation occurs. During cyclic photophosphorylation, electrons from photosystem I are not passed to NADP from the electron acceptor (as NADP is no longer available in oxidised state to receive the electrons). Instead, the electrons are transferred back to P_{700}. This downhill movement of electrons from an electron acceptor to P_{700} results in the formation of ATP from ADP, and is termed as cyclic

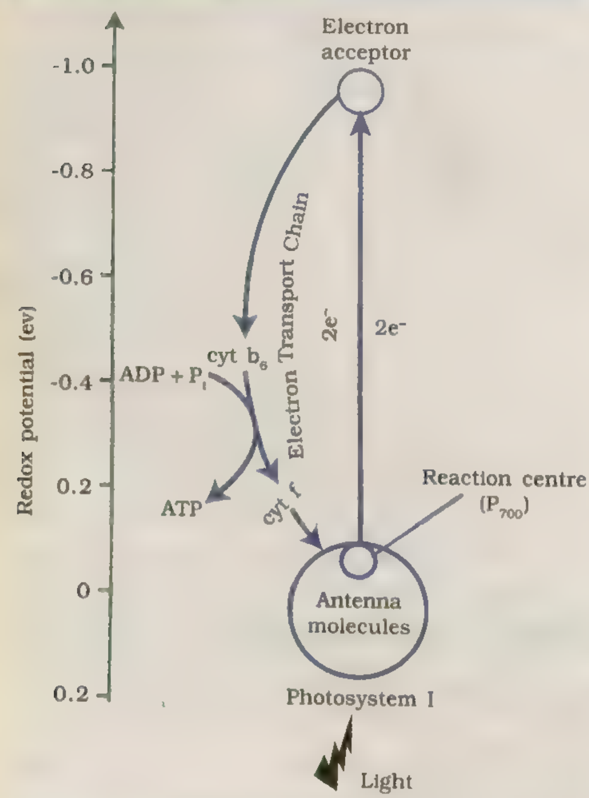


Fig. 3.6 *Cyclic photophosphorylation*

photophosphorylation (Fig. 3.6). It may be noted that in cyclic photophosphorylation, oxygen is not released (as there is no photolysis of water) and NADPH is also not produced.

Biosynthetic Phase *(Dark reactions)*

We have learnt in the previous section how ATP and NADPH are formed during the photochemical reactions in chloroplasts. Both ATP and $NADPH_2$ are essential requirements for the assimilation of CO_2 to carbohydrates. The reactions catalysing the assimilation of CO_2 to carbohydrates take place in the stroma, where all the necessary enzymes are localised. These reactions are referred to as dark reactions, leading to the photosynthetic reduction of carbon to carbohydrates.

In the first phase of carbon reactions, CO_2 is accepted by a 5-carbon molecule, ribulose-1, 5-bisphosphate (RuBP) and two molecules of 3-carbon compound, i.e., 3-phosphoglycerate (PGA) are formed (Fig. 3.7). This 3-carbon molecule is the first stable product of this pathway, and hence it is called **C_3 pathway** . Such plants which fix Co_2 using the C_3 pathway are called **C_3 plants**. The formation of PGA is called as **carboxylation**. This reaction is catalysed by an enzyme called **ribulose bisphosphate carboxylase oxygenase** (**Rubisco**). In addition to the carboxylase activity, this enzyme also possesses oxygenase activity, and hence abbreviated as Rubisco (ribulose bisphosphate carboxylase oxygenase). The oxygenase activity of the enzyme allows O_2 to compete with CO_2 for combining with RuBP (photorespiration).

After the carboxylation reaction, **reduction** of PGA occurs, where ATP and $NADPH_2$ formed during the photochemical reactions are utilised. With the reduction of PGA, glyceraldehyde-3-phosphate is formed. These 3-carbon molecules, also called **triose phosphates**, are diverted from the Calvin cycle and act as precursors for the synthesis of sucrose and starch. To complete the cycle, and for the cycle to continue on its own, **regeneration** of the initial 5-carbon acceptor molecule, that is RuBP, takes place. The regeneration of RuBP from glyceraldehyde-3-phosphate requires another ATP molecule

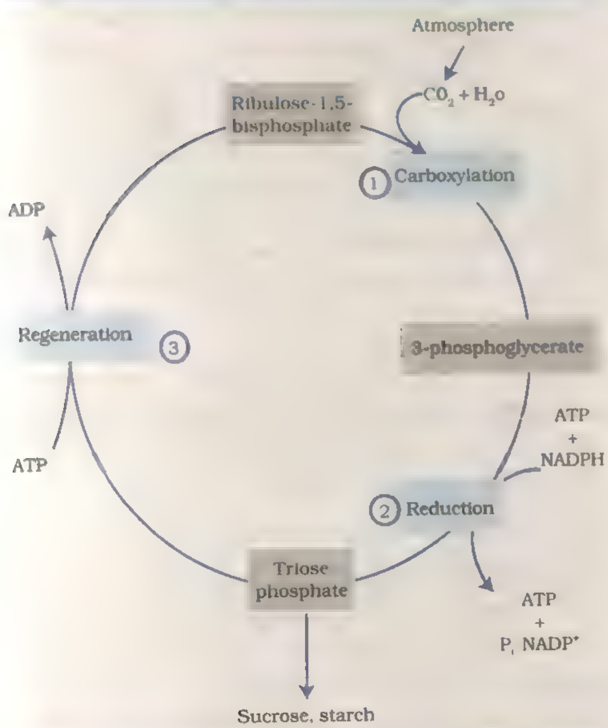


Fig. 3.7 *The Calvin cycle proceeds in three stages : (1) carboxylation, during which CO_2 combines with ribulose-1,5-bisphosphate; (2) reduction, during which carbohydrate is formed at the expense of the photochemically made ATP and NADPH; and (3) regeneration during which the CO_2 acceptor ribulose-1,5-bisphosphate is formed again so that the cycle continues*

formed as a result of photophosphorylation during the light reactions.

The C_3 type of carbon reactions occur in the stroma of chloroplast. This C_3 pathway is also called **Calvin cycle** after its discoverer, Melvin Calvin, who received Nobel Prize for discovering this pathway.

3.4 Photorespiration

We know by now that the enzyme Rubisco catalyses the carboxylation reaction, where CO_2 combines with RuBP for the Calvin cycle to initiate. But, this enzyme also has the ability to catalyse the combination of O_2 with RuBP, called **oxygenation** (Fig. 3.8). Respiration that is initiated in chloroplasts under high light conditions, is called **photorespiration**. This occurs essentially because of the fact that the active site of enzyme Rubisco is the same for both carboxylation and oxygenation. The oxygenation of RuBP in the presence of O_2 is the first reaction of photorespiration, which leads to the formation of one molecule of phosphoglycolate, a two-carbon compound and one molecule of PGA. While the PGA is used up in the Calvin cycle, the phosphoglycolate is dephosphorylated to form glycolate in the chloroplast (Fig. 3.9). From the chloroplast, the glycolate is diffused to **peroxisome**, where it is oxidised to glyoxylate. In the peroxisome, the glyoxylate is used to form the amino acid, glycine. Glycine enters

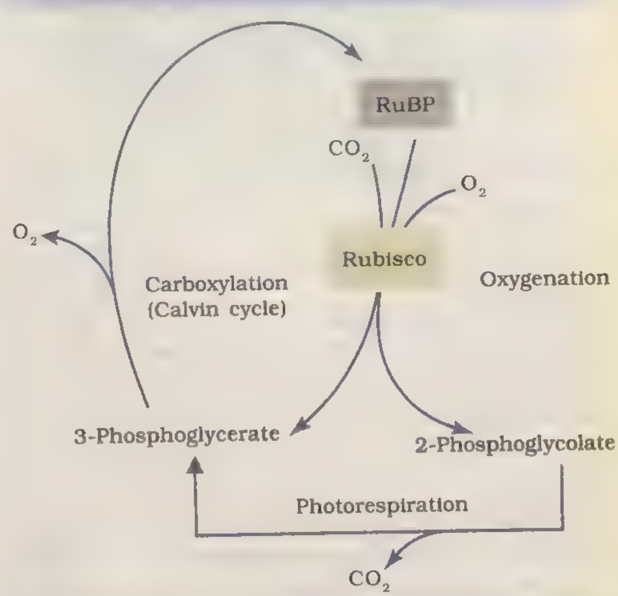


Fig. 3.8 *Photorespiration involves oxygenation of ribulose-bisphosphate catalysed by the enzyme Rubisco. The reactions lead to the formation of 2-phosphoglycolate, oxidation of which results in release of CO_2. In contrast, carboxylation, also catalysed by Rubisco, results in fixation of CO_2 for the production of carbohydrate*

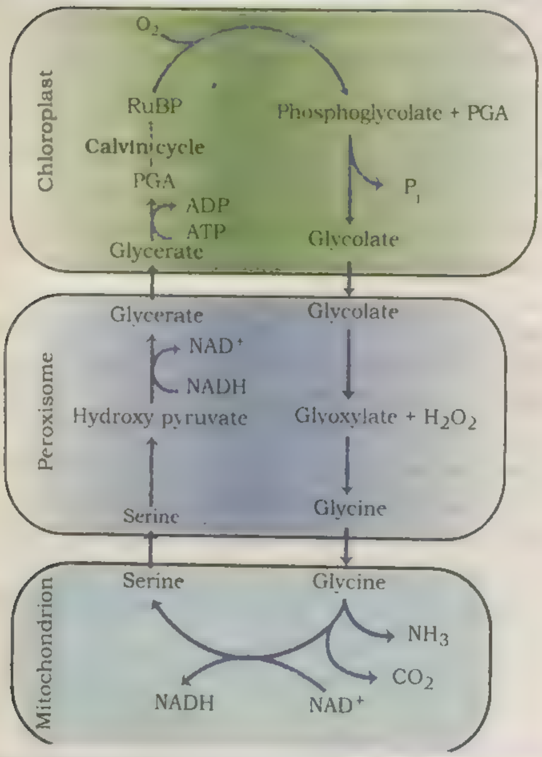


Fig. 3.9 *The photorespiratory pathway*

mitochondria where two glycine molecules (4 carbons) give rise to one molecule of serine (3 carbons) and one CO_2 (one carbon). The serine is taken up by the peroxisome, and through a series of reactions, is converted to glycerate. The glycerate leaves the peroxisome and enters the chloroplast, where it is phosphorylated to form PGA. The PGA molecule enters the Calvin cycle to make carbohydrates, but one CO_2 molecule released in mitochondria during photorespiration has to be re-fixed. In other words, 75 per cent of the carbon lost by the oxygenation of RuBP is recovered, and 25 per cent is lost as release of one molecule of CO_2.

Photorespiration is also called **photosynthetic carbon oxidation cycle**, and, as discussed above, involves an interaction of three organelles – chloroplast, peroxisome and mitochondria. Under conditions of high light and limited CO_2 supply, photorespiration has a useful role in protecting the plants from photooxidative damage. This means that if enough CO_2 is not available to utilise light energy for carboxylation to proceed, the excess energy causes damage to plants. However, photorespiration, that is oxygenation of RuBP, utilises part of the light energy and saves the plant from the photooxidative damage.

The relative levels of O_2 and CO_2 determine the occurrence of photorespiration, since both gases compete for the same active site of Rubisco. Increased O_2 level increases photorespiration, whereas increased CO_2 level decreases photorespiration (and increases C_3 photosynthesis).

3.5 C_4 Pathway

Photorespiration, which primarily occurs in C_3 plants, leads, as discussed above, to a 25 per cent loss of the fixed CO_2. It takes place in C_3 plants because of the fact that the enzyme Rubisco catalyses both carboxylation and oxygenation of the initial acceptor molecule, that is RuBP. As we know now, photosynthesis has two types of reactions : light reactions and carbon reactions. In the light reactions, ATP and $NADPH_2$ are produced, and O_2 is released as a by-product, as a result of photolysis of H_2O. During carbon reactions, CO_2 is assimilated to produce carbohydrates. Since both light reactions and carbon reactions occur in mesophyll cells in C_3 plants, it becomes inevitable for the enzyme Rubisco to catalyse simultaneously, both oxygenation and carboxylation of RuBP.

In certain category of plants called C_4 plants such as maize, sugarcane, pearl millet, amaranth, etc., nature has evolved a wonderful mechanism to avoid the occurrence of photorespiration, which is considered to be a wasteful process. In these, plants the first stable compound formed after carboxylation is a 4-carbon compound. This mechanism requires the presence of two types of photosynthetic cells, that is, mesophyll cells and bundle-sheath cells (Fig. 3.10). The bundle-sheath cells are arranged in a wreath-like manner. This kind of arrangement is called **Kranz anatomy**

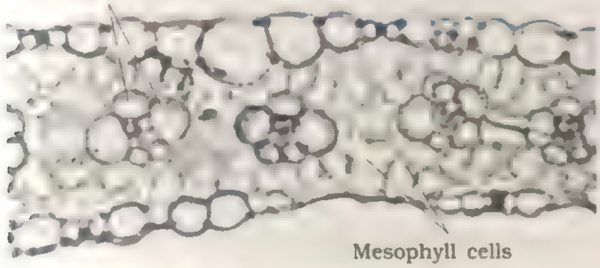


Fig. 3.10 *Transverse section of maize leaf showing the arrangement of mesophyll and bundle-sheath cells. The C_4 pathway takes place in the mesophyll cells, and the C_3 pathway (Calvin cycle) operates in the bundle-sheath cells. Both types of cells contain chloroplasts. Note that maize is a C_4 plant*

(*Kranz* : wreath). C_3 plants lack bundle sheath. The C_4 plants contain dimorphic chloroplasts, that means, chloroplasts in mesophyll cells are granal, whereas in bundle-sheath cells they are agranal. The granal chloroplasts contain thylakoids that are stacked to form grana (as in C_3 plants), but in agranal chloroplasts, grana are absent and the thylakoids are present only as stroma lamelle. The presence of two types of cells allows the occurrence of light reactions and carbon reactions separately in each type. As a result, release of O_2 takes place in the mesophyll, while the CO_2 fixation catalysed by Rubisco occurs in the bundle sheath. In C_4 plants, light reactions occur in mesophyll cells, whereas the CO_2 assimilation is carried out in bundle-sheath cells. This type of cellular arrangement does not allow O_2 released in mesophyll cells to escape to bundle-sheath cells. Thus, Rubisco, which is present only in bundle-sheath cells, does not come into contact with O_2, and as a result, oxygenation of RuBP is completely avoided. To further reduce the occurrence of photorespiration (oxygenation of RuBP), C_4 plants have been endowed with a

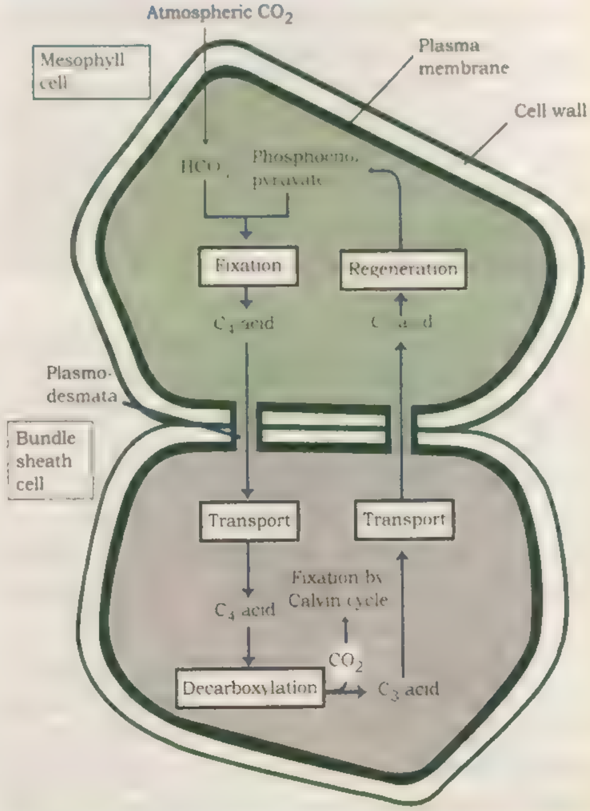


Fig. 3.11 *The C_4 photosynthetic carbon cycle involves two cell types and proceeds in four stages : (a) fixation of CO_2 into a 4-carbon acid in the mesophyll cells; (b) transport of the 4-carbon acid from the mesophyll cells to the bundle-sheath cells; (c) decarboxylation of the 4-carbon acid, generating a high concentration of CO_2 in the bundle-sheath cells; and cells, and regeneration of the CO_2 acceptor, phosphoenol pyruvate, to continue the cycle (d) transport of the residual 3-carbon acid back to the mesophyll*

CO_2 concentrating mechanism. This CO_2 concentrating mechanism is called **C_4 pathway**. Operation of the C_4 pathway, however, requires the cooperation of both cell types, that is, mesophyll and bundle-sheath cells. The objective of this pathway is to build up high

concentration of CO_2 in the vicinity of Rubisco in the bundle-sheath cells. High concentration of CO_2 near Rubisco favours carboxylation and suppresses photorespiration.

In C_4 pathway, CO_2 from the atmosphere enters through open stomata into the mesophyll cells, where it combines with phosphoenol pyruvate (3-carbon compound) in a reaction catalysed by the enzyme phosphoenol pyruvate carboxylase, (**PEPCase**) to form a C_4 acid, oxaloacetic acid (OAA) as shown in Figure 3.11. This reaction occurs in cytosol of the mesophyll cells and is called **fixation** of CO_2 or **carboxylation**, to give rise to the first stable product of the pathway, which is a C_4 compound, and hence the name C_4 pathway. The OAA is then converted into malate or aspartale (both C_4 acids) and then transported. The next step is the **transport** of the OAA from the cytosol of mesophyll cells to bundle-sheath cell chloroplasts. The C_4 acid is decarboxylated to release the fixed CO_2, thus generating high concentration of CO_2 near Rubisco. The other product of the decarboxylation reaction, the 3-carbon compound (pyruvic acid or pyruvate) is transported back to the mesophyll cells, where it is used in regenerating phosphoenol pyruvate for the pathway to continue on its own.

The C_4 photosynthetic pathway is more efficient than the C_3 pathway due to the absence of photorespiration in C_4 plants. Major differences in the C_3 and C_4 pathways are summarised in Table 3.1.

3.6 Crassulacean Acid Metabolism

Crassulacean acid metabolism (CAM) refers to a mechanism of photosynthesis that is different than already discussed C_3 and C_4 pathways. This occurs only in succulents and other plants that normally grow in dry conditions. In CAM plants, CO_2 is taken up by the leaves on green stems through stomata, which remain open in the night. However, during the day, the stomata remain closed in these plants to conserve moisture. The CO_2 taken up in the night is fixed in the same way as it happens in C_4 plants to form malic acid, which is stored in the vacuole (Fig. 3.12). The malic acid thus formed during the night, is used during the day as a source of CO_2 for photosynthesis to proceed via the C_3 pathway. Thus, CAM is a kind of adaptation

Table 3.1 : Difference between C_3 and C_4 Photosynthetic Pathways

Features	C_3	C_4
Cell type	One (mesophyll)	Two (mesophyll and bundle-sheath)
Kranz anatomy	No	Yes
Chloroplasts	One type (granal only)	Two types (granal and agranal)
CO_2 acceptor	RuBP	PEP
First CO_2 fixation product	3-PGA (3C compound)	Oxaloacetic acid (4C compound)
Carboxylase enzyme	Rubisco	PEPcase; Rubisco
CO_2 fixation rate	Low	High
O_2 inhibition of photosynthesis	Yes	No
Photorespiration	High	Negligible
Productivity	Low	High
CO_2 compensation point	High (25-100 µl CO_2 $.l^{-1}$)	Low (0-10 µl CO_2 $.l^{-1}$)
Temperature optimum	20-25°C	30-45°C
Examples	Rice, wheat, potato	Maize, pearl millet, amaranth

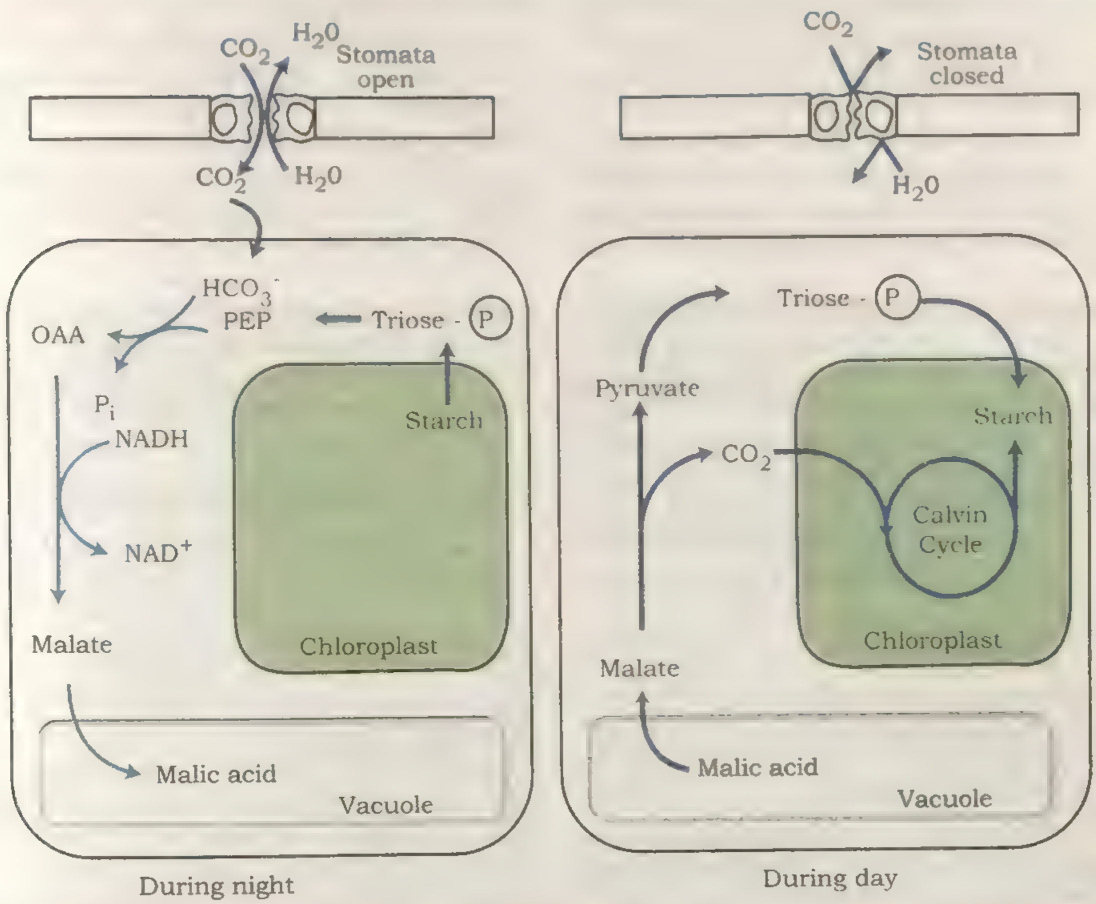


Fig. 3.12 *Crassulacean Acid Metabolism (CAM) pathway showing CO_2 uptake through open stomata during night and its utilisation for the formation of malic acid which is stored in the vacuole. During day, the malic acid is decarboxylated to release CO_2 which is re-fixed to produce starch inside chloroplast via C_3 Calvin cycle*

that allows certain plants (for example, pineapple) to carry out photosynthesis without much loss of water, which is inevitable in plants with C_3 and C_4 mechanisms.

3.7 Factors Affecting Photosynthesis

Photosynthesis is influenced by both environmental and genetic factors. The environmental factors include light, availability of CO_2, temperature, soil, water and nutrient supply. Genetic factors are all related with leaf and include leaf age, leaf angle and leaf orientation. According to F.F. Blackman, who postulated **Law of Limiting Factors** in 1905, photosynthesis is affected by several environmental and other factors but the role of photosynthesis is limited by the slowest step in the pathway, or the most limiting factor. This means that at a given time, only the factor that is most limiting among all will determine the rate of photosynthesis. For example, if CO_2 is available in plenty but light is limiting due to

cloudy weather, the rate of photosynthesis under such a situation will be controlled by the light. Furthermore, if both CO_2 and light are limiting, then the factor which is the most limiting of the two, will control the rate of photosynthesis.

Light

Both quality and intensity of light influence photosynthesis. Light between the wavelength of 400 nm and 700 nm is most effective for photosynthesis, and this light is called **photosynthetically active radiation (PAR)**. With regard to light intensity, it has a direct relationship with the rate of photosynthesis. As the intensity of light ($\mu mol.m^{-2}.s^{-1}$) increases, the rate of photosynthesis (CO_2 uptake, $\mu molCO_2.m^{-2}.s^{-1}$) increases. However, this direct relationship is not seen at higher light intensities. At higher light intensities, the rate of photosynthesis decreases. This is because of two reasons :

(i) other factors required for photosynthesis become limiting, and
(ii) destruction of chlorophyll occurs.

When the intensity of light falling on leaf increases beyond a point, chlorophyll is destroyed. This phenomenon occurs in the presence of O_2 and is called **photooxidation**. Carotenoids play a protective role by absorbing the excess light and diverting it away from chlorophyll, preventing photooxidation. The carotenoids also act as antioxidants, and help detoxify the bad effect of activated O_2 species on chlorophyll molecules.

Temperature

Photochemical reactions and carbon reactions of photosynthesis respond differently to temperature. While the photochemical reactions in thylakoid membrane remain largely unharmed by temperature, the enzymatic carbon reactions in stroma get influenced adversely. Overall, the process of photosynthesis is sensitive to higher temperatures, primarily because of the fact that at higher temperatures enzymes become inactive. Affinity of the enzyme Rubisco for CO_2 is also reduced at higher temperature. Low temperature also inactivates enzymes. The sensitivity of C_4 photosynthesis to low temperature, as compared to C_3 plants is due to a particular enzyme (pyruvate phosphate dikinase) that is required in the C_4 pathway.

In general, different habitats show different response of photosynthesis to a given temperature. For example, plants adapted to colder environments show a higher photosynthetic rate at low temperatures than plants adapted to higher temperatures.

Carbon Dioxide

The current level of atmospheric CO_2 is about 0.036 per cent or 360 $\mu l.l^{-1}$ (360 ppm), which is very low as compared to the concentration of other gases in the atmosphere, such as O_2 (about 20 per cent) and nitrogen (nearly 80 per cent).

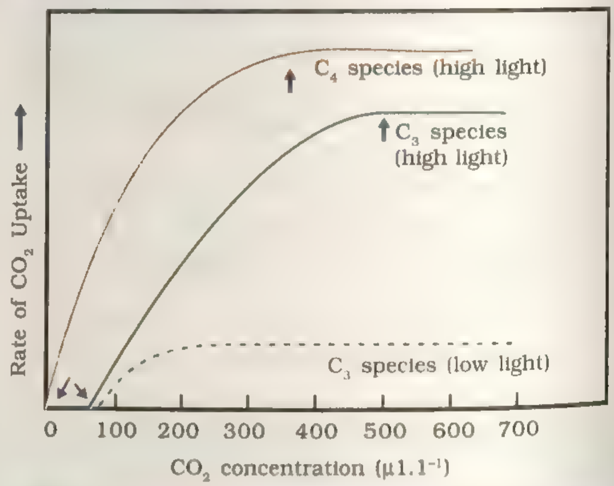


Fig. 3.13 Response of C_3 and C_4 plants to CO_2 concentration measured as rate of CO_2 uptake. Thick arrows (↑) show the CO_2 concentration at which the rate of photosynthesis get saturated under high light in C_3 and C_4 plants. Thin arrows (↓) show the CO_2 compensation point in C_3 and C_4 plants. CO_2 compensation point refers to CO_2 concentration at which the rate of photosynthesis just balances the rate of respiration, i.e., at this CO_2 concentration, the rate of CO_2 release during respiration is equal to the rate of CO_2 uptake in photosynthesis

The photosynthetic response of C_3 and C_4 plants to the available CO_2 concentration is variable (Fig. 3.13). In C_3 plants, rate of photosynthesis increases with an increase in CO_2 concentration (up to at least 500 $\mu l.L^{-1}$) when other factors are not limiting. This increased rate of photosynthesis in C_3 plants is primarily due to two factors :

(i) high availability of substrate for the carboxylation reaction; and
(ii) reduced photorespiration due to more available CO_2 to Rubisco.

In C_4 plants also, photosynthesis increases as the concentration increases. However, the C_4 plants attain saturation at much lower CO_2 concentration (around the present level of 360 $\mu l.L^{-1}$) than the C_3 plants, which become saturated at CO_2 level of about 500 $\mu l.L^{-1}$. This means that the current availability of CO_2 in the atmosphere is a limiting factor for C_3 plants.

Photosynthesis is also influenced by the current increase in the atmospheric CO_2. It is expected that CO_2 concentration could reach to a level of about 600 $\mu l.L^{-1}$ by 2020. In such a case, the C_3 plants are likely to be benefitted more than the C_4 plants. Scientists have demonstrated that C_3 plants can grow faster and yield more due to higher rate of photosynthesis, when CO_2 concentration is raised to 600 $\mu l.L^{-1}$. The primary effect of increased atmospheric CO_2 levels on photosynthesis would be through an increase in the intercellular CO_2 concentration by an increased rate of diffusion of CO_2 into the leaf.

Soil Water

Availability of water in soil has a prominent effect on plant photosynthesis. If soil water becomes limiting, plants undergo water stress. Under conditions of water stress, the rate of photosynthesis declines because of two factors:

(i) stomatal closure and the resultant decrease in CO_2 supply, and
(ii) reduced leaf water potential.

Low leaf water potential reduces leaf expansion, which causes a significant reduction in the photosynthetic surface area.

Nutrient Supply

Among various nutrients, nitrogen has a direct relationship with photosynthesis. Since nitrogen is a basic constituent of chlorophyll and all enzymes involved in carbon reactions, any reduction in nitrogen supply to plants has an adverse effect on photosynthesis. The major enzyme of carbon metabolism in plants, that is, Rubisco, alone accounts for more than half of the total leaf nitrogen. In general, all essential elements affect the rate of photosynthesis.

Leaf Factors

Among various leaf factors, such as leaf age, leaf angle and leaf orientation, leaf age has the most prominent effect on photosynthesis. If leaf undergoes senescence (that means, it turns yellow due to ageing), loss of chlorophyll occurs. The photosynthetic enzymes also get deactivated, resulting in reduced photosynthesis in a senescent leaf.

3.8 Translocation of Photosynthates

Photosynthates or photoassimilates, i.e. the energy-rich carbon compounds formed during the process of photosynthesis, are transported out of the leaf to non-photosynthetic organs and tissues, such as roots, stem tissues and developing seeds and grains. This long distance transport of photosynthates occurs through phloem and is known as **translocation.** The translocation of photosynthates to storage organs plays a significant role in determining crop yield. Sucrose is the principal form of carbohydrates that is translocated from leaf to the non-photosynthetic plant organs. It is a non-reducing sugar, and chemically stable. Because of this property, sucrose does not react with other substances during translocation through phloem.

The photosynthates provide energy to tissues through respiration. In storage organs, they are stored in the form of starch or as other carbohydrates.

3.9 Significance of Photosynthesis

Photosynthesis is vital for life on planet earth. It helps conversion of the solar energy into organic matter, which makes bulk of the dry matter of any organism. The plant biomass or dry matter, derived

through photosynthesis supports humans and all other heterotrophic organisms living in the biosphere. Presence of oxygen in the atmosphere is also an outcome of photosynthesis. This oxygen is helpful to living organisms in two ways :

(i) in efficient utilisation of the energy-rich molecules (carbohydrates formed during photosynthesis) through respiration, and
(ii) in making ozone (O_3) in the outer layer of atmosphere, which helps in stopping the highly destructive ultraviolet (UV) rays from reaching the earth.

Without oxygen, life of all aerobic organisms including humans, is not possible. Agricultural productivity is also totally dependent on photosynthesis. Scientists are currently engaged in genetically manipulating this process for further increasing the productivity of agricultural crops.

3.10 Chemosynthesis

Another mode of obtaining energy in some species of bacteria is chemosynthesis, which is different from photosynthesis. The process of carbohydrate synthesis, in which the organisms use chemical reactions to obtain energy from inorganic compounds, is called **chemosynthesis**. For example, bacteria of the genus *Nitrosomonas* oxidise ammonia to nitrite. The energy released during oxidation, is used by the bacteria in the same way as plants use energy from sunlight during photosynthesis, for converting carbon dioxide to carbohydrates. Such bacteria are called **chemosynthetic autotrophs**.

SUMMARY

Photosynthesis is one of the most important biological processes occurring in plants, algae and some bacteria. During this process, carbon dioxide from the atmosphere is taken in by leaves through stomata, and is used for making carbohydrates, primarily sucrose and starch. The process occurs inside chloroplasts, where green pigments called chlorophyll, and other accessory pigments called carotenoids, are located on thylakoids often stacked to form grana. Chlorophyll, particularly chlorophyll *a*, which acts as reaction center, takes part in the photochemical reactions. Light energy is initially absorbed by various chlorophyll molecules and accessory pigments, and funneled to the reaction centers. Together, these pigments form two types of photosystems, called photosystem I and photosystem II. In photosystem I, chlorophyll *a* molecule, which absorbs light maximum at 700nm, acts as the reaction centre and is referred to as P_{700}. Chlorophyll *a* that has maximum absorption at 680nm, is the reaction centre in photosystem II and is referred to as P_{680}. The cascade of events during light reactions involves both photosystems I and II. During these photochemical reactions, splitting of water molecule initially occurs in the presence of light, and O_2 is released at the photosystem II site.

Electrons released due to splitting of water initiate the electron transport chain. This leads to the formation of ATP and $NADPH_2$, energy required for converting CO_2 to carbohydrates.

The chemical energy, also called assimilatory power, stored in the form of ATP and $NADPH_2$, is utilised for CO_2 assimilation to carbohydrates. The carbon reactions for the synthesis of carbohydrates from CO_2 take place in the stroma of chloroplasts, where all necessary enzymes are present, the most notable being ribulose bisphosphate carboxylase oxygenase (Rubisco). The enzyme Rubisco catalyses the initial carbon reaction, in which CO_2 combines with ribulose bisphosphate (RuBP), a 5-carbon compound. The product of this

reaction is a 3-carbon compound, 3-phosphoglycerate. Hence, this pathway of carbon reactions is called C_3 pathway or the Calvin cycle. Similarly, there is another pathway of CO_2 fixation called as C_4 pathway, which is different than the C_3 pathway. The first product of the C_4 pathway is a 4-carbon compound, oxaloacetic acid. Occurrence of C_4 pathway in certain plants (called C_4 plants) in nature is an outcome of a necessity. This necessity was to get rid off an apparently wasteful process of photorespiration. During photorespiration, there is a loss of fixed carbon (25 per cent loss) and no energy rich compound is produced.

There are certain environmental factors that affect the rate of photosynthesis in plants. Such factors include quality and intensity of light, CO_2, water and temperature. Some other factors, like age of leaf, chlorophyll content and nutritional status of leaves also affect the rate of photosynthesis.

The end product of photosynthesis is sucrose, which is synthesised in the cytosol of a mesophyll cell. Starch, however, is synthesised inside chloroplasts only under certain conditions. The sucrose moves from leaf to other organs of the plant, where it is used either for growth, or for storage in storage organs.

EXERCISES

1. (a) Tick (✓) the correct answer:

   O_2 evolved during photosynthesis is from

   (i) CO_2
   (ii) H_2O

   (b) Describe very briefly the contribution of the following scientists :

   (i) Jan Ingenhousz
   (ii) C.B. van Niel
   (iii) Joseph Priestley

2. Describe in detail how ATP and NADPH are formed during photochemical reactions?

3. Describe carbon reactions of the C_3 pathway. Does this pathway also operate in C_4 plants?

4. What is photorespiration? Describe the process in detail and link it with the Calvin cycle.

5. Describe briefly the experiment conducted by T.W. Englemann.

6. Give comparison between the following :
   (a) C_3 and C_4 pathways
   (b) Cyclic and non-cyclic photophosphorylation
   (c) Carboxylation and oxygenation
   (d) Anatomy of leaf in C_3 and C_4 plants

7. What is a photosystem? Which is the pigment that acts as reaction centre? Describe the interaction of photosystem I and photosystem II.

8. What led to the evolution of C_4 pathway of photosynthesis? Describe in detail.

Chapter 4

Respiration

In Chapter 3, you have studied that light energy is converted into chemical energy, that is stored in the bonds of complex organic molecules of carbohydrates like glucose and starch. The breaking of the C-C bonds of such compounds through oxidation releases a considerable amount of energy for utilisation by plants. This phenomenon of release of energy by oxidation of various organic molecules, for cellular use, is known as **respiration**. The compounds that are oxidised during this process, are known as **respiratory substrates.** The whole of energy contained in respiratory substrates is not released all at once. It is released slowly in a stepwise series of reactions controlled by enzymes. During the process of respiration, oxygen is utilised, and carbon dioxide, water and energy are released as products. This energy is utilised in various energy-requiring processes of the organisms, and the carbon skeleton produced during respiration is used as precursors for biosynthesis of other molecules in the cell. The reaction that occurs in common respiration of glucose can be summed up in the following equation :

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + \text{Energy} \quad (2870 \text{ kJ})$$

In this chapter, you will study different types of respiration, respiratory quotient and the mechanism of respiration.

4.1 Types of Respiration

Depending upon the availability of oxygen, respiration is classified into two major types:

(i) Aerobic respiration

(ii) Anaerobic respiration

Aerobic Respiration : This process of respiration, which leads to a complete oxidation of organic substances in the presence of oxygen, and releases CO_2, water and a large amount of energy present in the substrate. This type of respiration is the most common in higher organisms.

Anaerobic Respiration : This type of respiration takes place in the complete absence of oxygen. It generally occurs in lower organisms, such as bacteria and fungi. It also occurs in higher plants and animals under certain conditions, particularly when O_2 is limiting. In anaerobic respiration, the carbohydrate is incompletely oxidised into some carbonic compounds, such as ethyl alcohol or acetic acid or lactic acid and CO_2, and the amount of energy released is also much less as compared to aerobic respiration. This process can be shown by the following equation :

$$C_6H_{12}O_6 \longrightarrow 2C_2H_5OH + 2CO_2 + \text{Energy (247 kJ)}$$

This process of oxidation in microbes is known as **fermentation**, which is very much similar to that of anaerobic respiration in the case of higher plants.

4.2 Respiratory Quotient

As you know, during aerobic respiration, O_2 is consumed and CO_2 is released. The ratio of the volume of CO_2 evolved to the volume of O_2 consumed in respiration is called **respiratory quotient** (RQ) or **respiratory ratio**.

$$RQ = \frac{\text{Volume of } CO_2 \text{ evolved}}{\text{Volume of } O_2 \text{ consumed}}$$

The respiratory quotient depends upon the type of respiratory substrate used during respiration. This is different for different substrates.

Carbohydrates : When carbohydrates are used as substrate and are completely oxidised, the RQ will be 1, because equal amounts of CO_2 and O_2 are evolved and consumed, respectively, as shown in the equation below :

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + \text{Energy}$$

$$RQ = \frac{6CO_2}{6O_2} = 1.0$$

Fats : When fats are used in respiration, the RQ is less than 1. For example, it is explained below with tripalmitin (2 molecules) as a substrate.

$$2(C_{51}H_{98}O_6) + 145O_2 \longrightarrow 102CO_2 + 98H_2O + \text{Energy}$$
Tripalmitin

$$RQ = \frac{102CO_2}{145O_2} = 0.7$$

The RQ in this case is less than 1 because fats contain less oxygen than the carbohydrates. Therefore, they require relatively greater amount of O_2 for oxidation.

Organic acids : When organic acids, such as oxalic acid and malic acid, serve as respiratory substrates, then RQ is more than one. It is because organic acids contain more oxygen than carbohydrates. Therefore, relatively less amount of oxygen is required for their oxidation.

$$2(COOH)_2 + O_2 \longrightarrow 4CO_2 + 2H_2O + \text{Energy}$$
(Oxalic acid)

$$RQ = \frac{4CO_2}{1O_2} = 4$$

Note that in anaerobic respiration, CO_2 is evolved but oxygen is not used. Therefore, RQ, in such a case, will be infinite. For example,

$$C_6H_{12}O_6 \xrightarrow{\text{Zymase}} 2C_2H_5OH + 2CO_2 + \text{Energy}$$
(Glucose)

$$RQ = \frac{2CO_2}{0O_2} = \text{Infinity} (\infty)$$

4.3 Mechanism of Respiration

In the process of respiration, the carbohydrates are converted into pyruvic acid through a series

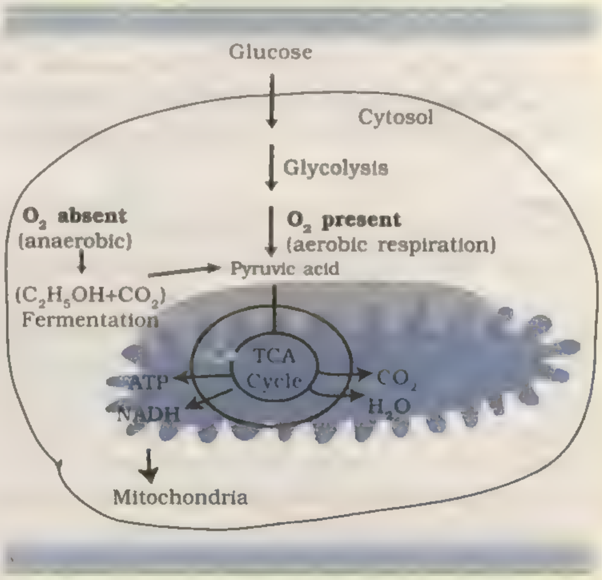


Fig. 4.1 *The broad scheme of respiration*

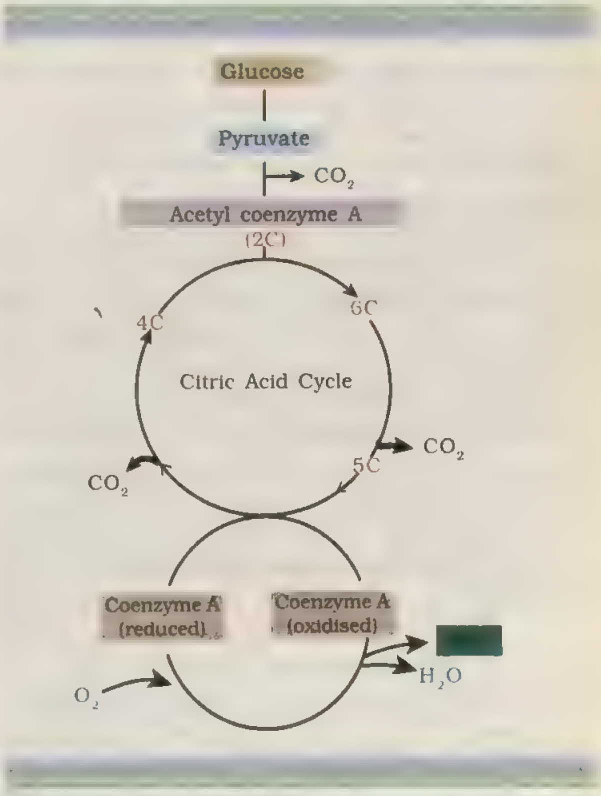


Fig. 4.2 *The steps of respiration at a glance*

of enzymatic reactions. These reactions, put together, are known as **glycolysis** and take place in the cytosol. The pyruvic acid thus formed enters mitochondria, where O_2 and the necessary enzymes are available, and pyruvic acid is finally converted into CO_2 and H_2O. This reaction series is known as **Krebs cycle** or **tricarboxylic acid** (TCA) or **citric acid cycle**. The general scheme of respiration is shown in Figures 4.1 and 4.2.

Glycolysis : The term glycolysis has originated from the Greek words, *glycos* for sugar, and *lysis* for splitting. The scheme of glycolysis was given by Gustav Embden, Otto Meyerhof, and J. Parnas, and is often referred to as the EMP pathway, after the abbreviation of their last names. Glycolysis is the first stage in the breakdown of glucose and is common to all organisms. In anaerobic organisms, it is the only process in respiration. Glycolysis occurs in cytoplasm of the cell. In this process, glucose undergoes partial oxidation to form two molecules of pyruvic acid. In plants, this glucose is derived from sucrose, which is the end product of photosynthetic carbon reactions, or from storage carbohydrates. Sucrose is converted into glucose and fructose by the enzyme **invertase**, and these two monosaccharides can readily enter the glycolytic pathway. The various steps of glycolysis are depicted in Figure 4.3.

Glucose and fructose are phosphorylated to give rise to glucose-6-phosphate and fructose-6-phosphate, respectively, by the activity of the enzyme **hexokinase**. The phosphorylated form of glucose then isomerises to produce fructose-6-phosphate. Subsequent steps of metabolism of glucose and fructose are same. Fructose-6-phosphate is phosphorylated and fructose-1, 6-bisphosphate produced by the action of the enzyme **phosphofructokinase**, is split into two molecules of triose phosphate, that is, 3-phosphoglyceraldehyde and dihydroxyacetone phosphate, which are interconvertible.Once 3-phosphoglyceraldehyde is formed, the glycolytic pathway enters the energy conserving phase, and it is oxidised to a carboxylic acid (1, 3-bisphosphoglycerate),

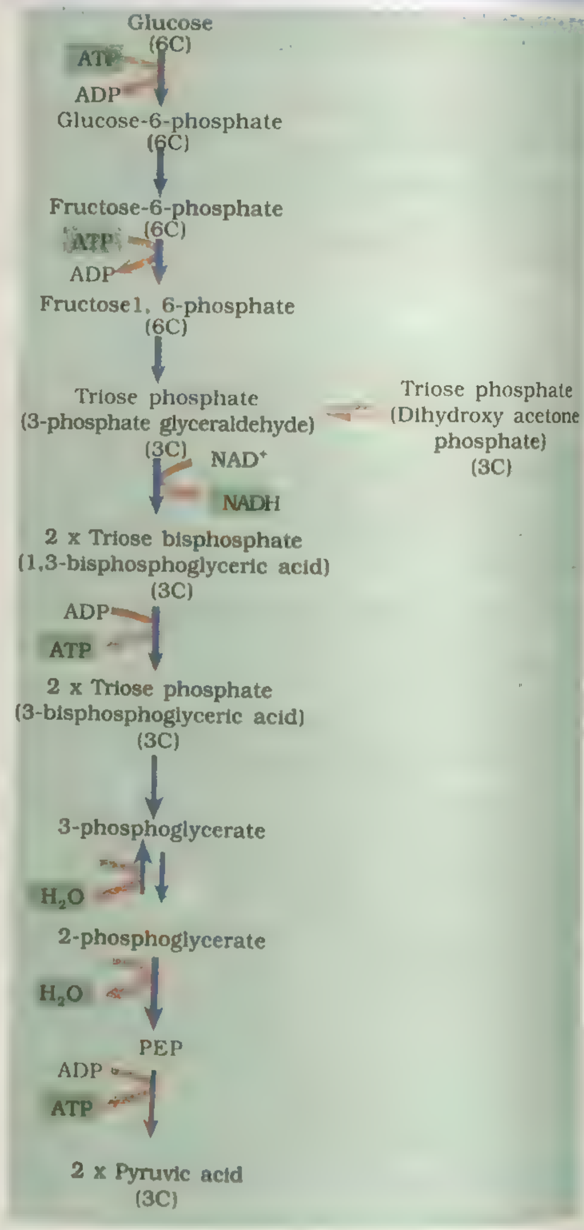


Fig. 4.3 *Major steps of glycolysis*

and NAD^+ is reduced to NADH. In the next step of glycolysis, phosphoglycerate kinase catalyses the formation of 3-phosphoglycerate from 1, 3-bisphosphoglycerate, generating ATP in the process. This type of ATP generation, whereby a phosphate group is directly transferred from substrate to ADP to form ATP,

is distinctly different from the ATP produced by ATP synthase during oxidative phosphorylation in mitochondria (described later in this chapter) or photophosphorylation in chloroplasts (see Chapter 3). Subsequently, 3-phosphoglycerate is successively converted into 2-phosphoglycerate and phosphoenolpyruvate (PEP). PEP is a good donor for the formation of ATP. Using PEP as substrate, the enzyme pyruvate kinase catalyses the formation of pyruvate and liberates ATP.

In the above pathway, the molecules of ATP are produced in two ways:

(i) direct transfer of phosphate to ADP, and
(ii) oxidation of NADH produced during glycolysis to NAD^+.

Each molecule of NADH gives rise to three molecules of ATP. In the glycolysis scheme described, it is obvious that two triose phosphate molecules are formed from one glucose molecule, and 4 ATP molecules are produced. Out of these 4 ATP molecules, 2 ATP molecules are consumed initially in converting glucose to fructose-1, 6-bisphosphate. In addition, three molecules of ATP are produced from the oxidation of each of the two molecules of NADH produced during catabolism of glucose. Therefore, a net gain of 8 ATP molecules occurs during glycolysis.

Fermentation

No doubt, glycolysis can also function without O_2, but further oxidation of pyruvic acid and NADH by mitochondria requires oxygen. Therefore, when O_2 is limiting, NADH and pyruvic acid begin to accumulate. Under this condition, plants carry out **fermentation** (anaerobic respiration), leading to the formation of CO_2 and either ethanol or lactic acid (usually ethanol). During fermentation, the pyruvic acid releases one molecule of CO_2 to produce acetaldehyde. The acetaldehyde, then reoxidises NADH, and is itself reduced to ethanol. These reactions are catalysed by the enzymes, pyruvic acid decarboxylase and alcohol dehydrogenase. The steps involved are shown in Figure 4.4.

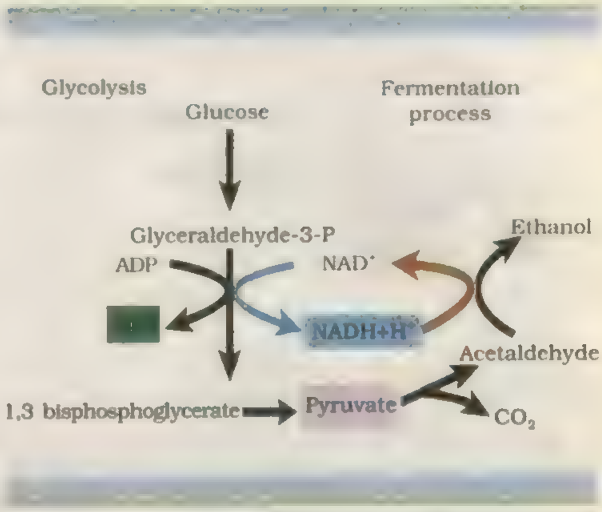


Fig. 4.4 *Pathway of anaerobic respiration in yeast (Fermentation)*

Aerobic Oxidation of Pyruvic Acid

Pyruvic acid, generated in the cytosol, is transported to mitochondria, and thus initiates the second phase of respiration. You have already studied the structure of mitochondria in Class XI. Before pyruvic acid enters Krebs cycle, operative in the mitochondria, one of the three carbon atoms of pyruvic acid is oxidised to carbon dioxide in a reaction called **oxidative decarboxylation**, that is, pyruvate is first decarboxylated, and then oxidised by the enzyme pyruvate dehydrogenase. The combination of the remaining 2-carbon acetate unit is readily accepted by a sulphur-containing compound, coenzyme A (CoA), to form acetyl-CoA. This is the connecting link between glycolysis and Krebs cycle. During the process, NAD^+ is reduced to NADH. The summary of the reaction is given below :

$$\text{Pyruvic acid} + \text{CoA} \xrightarrow[Mg^{2+}]{NAD^+ \ \ NADH} \text{Acetyl CoA} + CO_2$$

During this process, two molecules of NADH are produced (from the metabolism of two molecules of pyruvic acid produced during glycolysis), and thus, it results in a net gain of 6 ATP molecules (2NADH × 3 = 6 ATP).

Citric acid cycle : This was elucidated by the British biochemist, Hans Krebs, in 1937. This is also known as **tricarboxylic acid cycle** (TCA cycle) or **Krebs cycle**. The actual citric acid cycle begins when acetyl-CoA enters into a reaction to form citric acid. The elucidation

Sir Hans Adolf Krebs

(1900-1981)

Krebs, born in 1900, started his career as assistant to Warburg in Kaiser Wilhelm Institute of Physiology, Berlin. He served the universities of Sheffield and Oxford as Professor of biochemistry.

He established the central role of pyruvate in conversion of glucose hydrogens into fumarate. He also discovered catalytic role of pyruvate. The citric acid cycle for production of energy in the cell was described by him and is known with an alternative name, Tricarboxylic Cycle (TCA) or Krebs Cycle. Krebs proposed this cycle based on the experimental findings in 1937, which showed that respiration was inhibited by malonate. He also demonstrated that it is a cycle and not a collection of unrelated reactions. He shared in 1953 Nobel prize for physiology and medicine with Fritz Lipmann mainly for discovery of TCA in living organisms. This added to the basic understanding of cell metabolism. His publication, *Energy Transformation in Living Matter* (1957), co-authored with Hans Kornberg, encouraged research in this field.

of this cycle explained how pyruvate is broken down to CO_2 and H_2O. It also highlighted the concept of cycles in metabolism. For this pioneering work, Hans Krebs was awarded the coveted Nobel Prize in 1953.

In the first reaction of citric acid cycle, one molecule of acetyl CoA combines with 4-carbon oxaloacetic acid (OAA), to form 6-carbon citric acid, and CoA is released. The reaction is catalysed by the enzyme citrate synthase. Citrate is then isomerised to isocitrate. It is followed by two successive steps of decarboxylation, leading to the formation of α-ketoglutaric acid and succinyl-CoA. In the remaining steps of citric acid cycle, succinyl-CoA is oxidised to OAA (Fig. 4.5), allowing the cycle to continue.

During this cycle, 3 molecules of NADH and one molecule of $FADH_2$ are reduced to produce NADH and $FADH_2$, respectively. These reduced electron carriers pass on the hydrogen atoms to oxygen through electron transport system, yielding 11 more ATP molecules for each molecule of pyruvic acid. In addition, one more ATP molecule is generated directly during the cycle, to give a total of 12 ATP molecules per

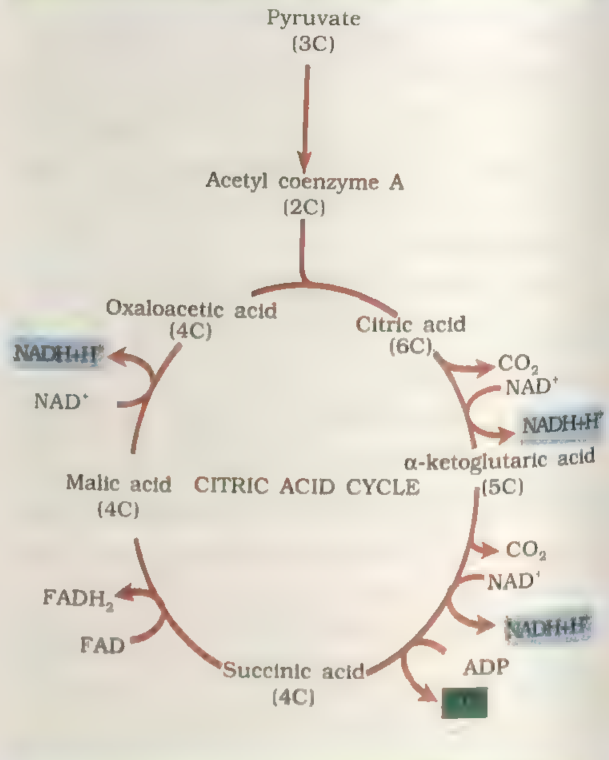


Fig. 4.5 The Citric acid cycle

pyruvic acid molecule (3C). As two molecules of pyruvic acid are produced from each molecule of glucose (6C), a total of 24 molecules of ATP are formed during the citric acid cycle.

NADH and $FADH_2$ so produced during the citric acid cycle are linked with the electron transport system and produce ATP by oxidative phosphorylation. The summary equation for this phase of respiration may therefore be written as follows :

$$\text{Pyruvic acid} + 4NAD^+ + FAD + 2H_2O + ADP + Pi \xrightarrow{\text{Mitochondrial Matrix}} 3CO_2 + 4NADH + 4H^+ + FADH_2 + ATP$$

Electron Transport System (ETS) and Oxidative Phosphorylation

The glucose molecule is completely oxidised by the end of the citric acid cycle. But the energy is not released unless NADH and $FADH_2$ are oxidised through the electron transport system. At this stage, it is better to explain the meaning of oxidation in terms of electrons. Here, oxidation of a compound means removal of electrons from it. This is usually accompanied by removal of hydrogen. Reduction means addition of electrons to a compound, usually accompanied by addition of hydrogen. The metabolic pathway through which the electron passes from one carrier to another, is called the **electron transport system** (ETS) (Fig. 4.6) and it is operative in the inner mitochondrial membrane. Electrons from NADH produced in the mitochondrial matrix during citric acid cycle are oxidised by an NADH dehydrogenase (**complex I**), and electrons are then transferred to ubiquinone located within the inner membrane. Ubiquinone also receives reducing equivalents via $FADH_2$ that is generated during oxidation of succinate, through the activity of the enzyme, succinate dehydrogenase (**complex II**), in the citric acid cycle. The reduced ubiquinone (ubiquinol) is then oxidised with the transfer of electrons to cytochrome *c* via cytochrome bc_1 complex (**complex III**). Cytochrome *c* is a small protein attached to outer surface of the inner membrane and acts as a mobile carrier for transfer of electrons between complex III and IV. **Complex IV** refers to cytochrome *c* oxidase

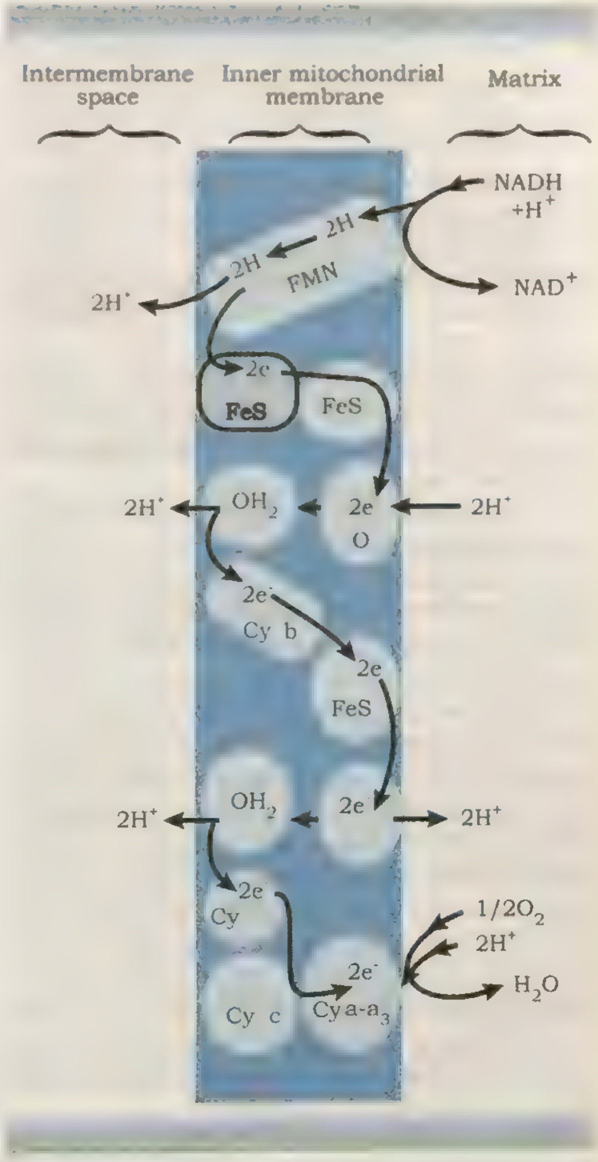


Fig. 4.6 *Electron transport system*

complex containing cytochromes *a* and a_3, and two copper centers.

When the electrons pass from one carrier to another via complex I to IV in the electron transport chain, they are coupled to ATP synthase (**complex V**) for the production of ATP from ADP and inorganic phosphate. The number of ATP molecules synthesised depends on nature of the electron donor. Oxidation of one molecule of NADH gives rise to 3 molecules of ATP, while that of one molecule of $FADH_2$ produces 2 molecules of ATP. During electron

transfer, the hydrogen atoms split into protons and electrons. The electrons are carried by the cytochromes. They recombine with their protons before the final stage, when hydrogen atom is accepted by oxygen to form water. Although the aerobic process of respiration takes place only in the presence of oxygen, the role of oxygen is limited to the terminal stage of the process. Yet, the presence of oxygen is vital, since it drives the whole process by removing hydrogen from the system. Oxygen acts as the final hydrogen acceptor. The whole process by which oxygen effectively allows the production of ATP by phosphorylation of ADP, is called **oxidative phosphorylation**.

The pathway of electron-transport system is summarised in Figure 4.6.

As mentioned earlier, the energy released during the electron transport system is utilised in synthesising ATP with the help of ATP synthase (complex V). This complex consists of two major components, F_1 and F_0 (Fig. 4.7). The F_1 headpiece is a peripheral membrane protein complex and contains the site for synthesis of ATP from ADP and inorganic phosphate. F_0 is an integral membrane protein complex that forms the channel through which protons cross the inner membrane. The passage of protons through the channel is coupled to the catalytic site of the F_1 component for the production of ATP. For each ATP produced, $2H^+$ pass through F_0 from the intermembrane space to the matrix down the electrochemical proton gradient.

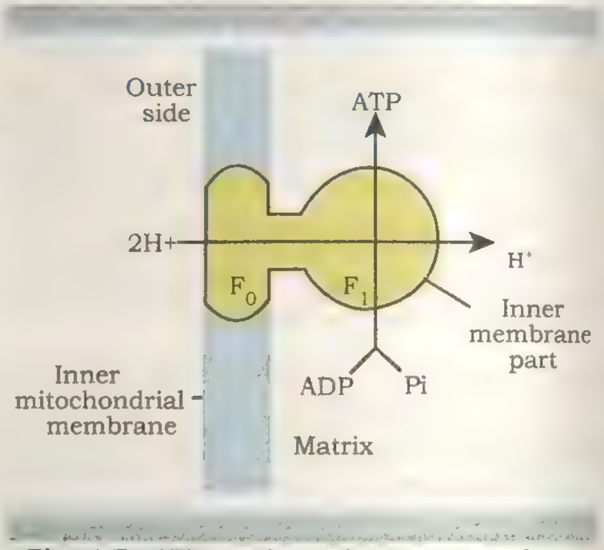


Fig. 4.7 *ATP synthesis by inner membrane particles of mitochondrion*

***Net gain of ATP* :** There is a net gain of 38 ATP molecules during aerobic respiration of one molecule of glucose. The details of ATP produced are given in the Table 4.1.

In most eukaryotic cells, 2 molecules of ATP are required for transporting the NADH produced in glycolysis into the mitochondrion for further oxidation. Hence, the net gain of ATP is 36 molecules.

Significance of Citric Acid Cycle

(i) During this pathway, carbon skeletons are obtained for use in growth and maintenance of the cell. Many intermediate compounds are formed, which are used in

Table 4.1 : ATP Molecules Produced during Respiration

Stage of Respiration	Source	Number of ATP Molecules Produced
Glycolysis	Direct 2-molecules of NADH (one molecule of NADH yields 3 molecules of ATP)	2 6
Pyruvic acid to acetyl-CoA	2 molecules of NADH	6
Citric acid cycle	6 NADH 2FADH (FADH produces only 2 molecules of ATP) Direct	18 4 2
Total yield of ATP molecules		38

the synthesis of other biomolecules like amino acids, nucleotides, chlorophyll, cytochromes and fats. For example, succinyl CoA is the starting molecule for synthesis of chlorophyll; amino acids are synthesised from α-ketoglutaric acid, pyruvic acid, and oxaloacetic acid.

(ii) This is the major pathway for generation of ATP molecules, the energy currency of the cell.

How Efficient is the System?

The total energy yield from 38 ATP molecules comes to 1292 kJ (one ATP molecule yields 34 kJ of energy). Energy released by one molecule of glucose on complete oxidation corresponds to 2870 kJ. Thus, the efficiency is 45 per cent. It shows that only a part of this energy is used to make ATP, and much of the energy generated during respiration is released in the form of heat.

4.4 Pentose Pathway

You have seen that glucose is broken down into CO_2 and water during aerobic respiration. This is the principal pathway of respiration. But sometimes, oxidation of glucose takes place by another pathway, which is called pentose phosphate pathway (PPP).

In pentose pathway, glucose-6-phosphate (6C) produced during the early stages of glycolysis, or the photosynthates produced during photosynthesis, are oxidised to give rise to 6-phosphogluconate. This reaction takes place in the presence of the enzyme, glucose-6-phosphate dehydrogenase, and generates NADPH. The 6-phosphogluconate molecule is further oxidised by the enzyme, 6-phosphogluconate dehydrogenase. As a result of this, one molecule each of ribulose-5-phosphate, carbon dioxide and NADPH are produced. Ribulose-5-phosphate undergoes many changes to produce glycolytic intermediate, such as glyceraldehyde-3-phosphate and fructose-6-phosphate. The various reactions of this cycle take place in the cell cytoplasm.

4.5 Compensation Point

At given low concentration of CO_2 and non-limiting light intensity, the photosynthetic rate of a given plant will be equal to the total amount of respiration (true respiration plus photorespiration). The atmospheric concentration of CO_2 at which photosynthesis just compensates for respiration, is referred to as the **CO_2 compensation point**. The CO_2 compensation point is reached when the amount of CO_2 uptake is equal to that generated through respiration at a non-limiting light intensity. Net photosynthesis under these conditions is zero. In C_3 plants, the CO_2 compensation point is usually much higher (25 to 100 $\mu l.L^{-1}$) than in C_4 plants (less than 5 $\mu l.L^{-1}$).

SUMMARY

Respiration is a metabolic process in which carbon compounds generated during photosynthesis are oxidised, in the presence of various enzymes, into carbon dioxide and water with the release of energy. The ratio of CO_2 evolved to the volume of O_2 consumed during the oxidation of carbon compounds is called respiratory quotient. The respiratory quotient depends upon the respiratory substrate being used in respiration. Respiration is basically of two types : (i) aerobic respiration that occurs in the presence of oxygen, and (ii) anaerobic respiration that does not require O_2.

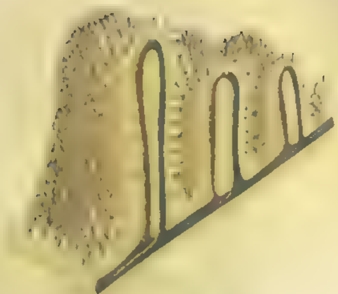
Anaerobic respiration takes place in the absence of oxygen. It occurs in the cytoplasm of the cell. The end products are ethanol or lactic acid, and very little energy is released. The initial steps, constituting glycolysis, are common to both

anaerobic and aerobic respiration. During glycolysis, glucose is converted into pyruvic acid. There is a net gain of 8 ATP molecules during this process.

Aerobic respiration occurs in the mitochondria. In the mitochondria, the pyruvic acid is oxidised to acetyl-CoA, which then enters the TCA or citric acid cycle where it is oxidised further. During this process, CO_2, and NADH and $FADH_2$ are produced and take part in the electron transport system (ETS) that carries the electrons in a chain to molecular oxygen, ultimately producing water. The energy released during ETS is utilised to synthesise ATP. This process is termed as oxidative phosphorylation. The energy trapped in ATP is utilised in various metabolic processes by the living organisms. Most organisms contain an alternate route also for glucose metabolism, called the oxidative pentose phosphate pathway. This pathway also operates in cytosol of the cell and produces pentose sugars and NADPH.

EXERCISES

1. Define the following :
   (a) Respiration
   (b) Respiratory substrate
   (c) Respiratory quotient
   (d) Anaerobic respiration
   (e) Aerobic respiration
   (f) Fermentation
2. Fill in the blanks with suitable words :
   (a) Pyruvic acid is oxidised into ______ before entering citric acid cycle.
   (b) The RQ is ________ if respiratory substrate is oxalic acid.
   (c) Glycolysis takes place in _________.
   (d) F_0-F_1 complex participate in the synthesis of ________.
   (e) The Acetyl CoA is accepted by _______ in the citric acid cycle.
3. Distinguish between the following :
   (a) Aerobic respiration and anaerobic respiration
   (b) Glycolysis and fermentation
   (c) Glycolysis and citric acid cycle
4. Why does anaerobic respiration produce less energy than aerobic respiration?
5. What is oxidative phosphorylation?
6. Describe the process and role of citric acid cycle in living organism.
7. Describe the pentose phosphate pathway.
8. Calculate the efficiency of respiration in the living system.
9. Write the significance of citric acid cycle.
10. Illustrate the mechanism of electron transport system.



UNIT SEVEN

PHYSIOLOGY OF ANIMALS

Naturalists have discovered and catalogued the animal species of the earth. The discovery of evolution of the stunning diversities has made the understanding of animal functions a challenging one. The concepts and principles lay the foundations for understanding how biological organisms govern various life activities, such as processing of materials and energy, interaction with the environments, growth and reproduction. Each type of life, from the very simple protist to the largest tree or to the highest evolved human being, has its own. The study of functional mechanisms of animals comes in the realm of animal physiology. The central theme of the present unit is the basic principles and mechanisms of animal physiology, with special emphasis on humans. This Unit will deal with nutrition, including the mode of collection of food, its processing respiration, including exchange of gases between the animals and external environment, and other associated aspects. It will explain the mechanism of circulation of body fluids and the related system. How the metabolic toxic wastes, produced in the body, are eliminated is as important as any other function of animals. The function of locomotion in animals requires skeletal support and muscular action. For nutrition, animals need food, for utilisation of food, they need enzymes and oxygen, for making the food and oxygen available to different cells, they need systems of transport and, above all, all such functioning require control and coordination. This unit will acquaint you with neuronal and chemical coordination of various functions in animals.

Earl W. Sutherland, Jr.

(1915-1974)

Earl W. Sutherland, Jr. was born at Burlingame, Kansas, U.S.A. in November 1915. Ever since the first hormone was discovered, the function of hormones has been a central theme of research for many scientists. Even after many years of discovery of insulin hormone, the mechanism of hormone action remained a mystery. Sutherland discovered a new chemical substance, cyclic Adenosine monophosphate (cAMP), and its function as a second messenger in 1965 long after discovery of insulin.

Sutherland, while studying the effect of adrenaline (epinephrine) on the formation of glucose in liver and muscle cells, discovered cAMP serving as an intermediate during the function of the hormone. He called it a "second messenger" since cAMP transmits signal from epinephrine to cells.

Sutherland suggested that cAMP participates as a second messenger in many hormone mediated reactions showing its effect beyond the action of adrenaline. Contemporary scientists did not agree with his generalisation; they found it difficult to visualise that a single chemical substance gives rise to all the variety of effects mediated by various hormones. Sutherland and many other scientists established evidence to show the formation of cyclic AMP in the cell membrane due to hormones. Actually, Sutherland had discovered a new biological principle, a general mechanism for the action of many hormones.

Earl W. Sutherland, Jr. was awarded the Nobel prize in physiology or medicine for 1971 "for his discoveries concerning the mechanisms of the action of hormones."

Chapter 5

Animal Nutrition

You can recall that plants synthesise their energy sources, that is high energy organic molecules (food), from low-energy inorganic raw materials available in their surroundings. These are self-sustaining **autotrophs** and their mode of nutrition is called **autotrophic nutrition**. On the other hand, acellular protozoans and animals feed on the high-energy organic molecules as food. These are **heterotrophs** and their kind of nutrition is known as **heterotrophic nutrition**. In this chapter, you will be introduced with the mode of nutrition in animals. At first, you will be familiarised with the various types of food and nutrients, along with their sources that are required by the animals and humans, in particular. This will include the role of different food and nutrients in the sustenance of humans. Following this, you will be acquainted with the general modes of nutrition in animals, including the types and steps of holozoic nutrition. Also, you will learn about the mechanism of digestion in cockroach. The next section will deal with the digestive system of humans, including discussions on mobility of gut, nature of gastrointestinal secretions, and enzymatic digestion of different types of food. Next, a brief introduction will be given regarding hormonal control of digestion, and the mechanism of absorption of the digested products and the fate of the undigested food. Finally, a section will be devoted on the nutritional requirements and the effect of nutritional deficiencies in humans.

5.1 Food and Nutrients of Animals

All animals, including humans, must garner an appropriate variety of food and nutrients. The chemical substances present in the food are called **nutrients**. In general, the very use of the nutrients by an organism for harvesting energy, building body substances for growth and development, and providing protection from diseases, is called **nutrition**. By and large, nutrients provide the metabolic energy and the raw materials for growth, repair of tissues, production of gametes and protection from diseases.

Types of Nutrients

Nutrients may be organic or inorganic in nature. The organic constituents of nutrients are carbohydrates, lipids, proteins and vitamins, and the inorganic constituents are minerals and water. Carbohydrates, lipids and proteins are **macronutrients** or **proximate principles of food** because these constitute the energy sources for the production of heat and different organic functions. Minerals, vitamins and water are **micronutrients** or **protective principles of food** because although these do not provide energy, yet their deficiencies are related to specific diseases and abnormalities in animals including humans. About 21 minerals (e.g. sodium, potassium, calcium, sulphur, phosphorus, magnesium and chlorine) or **macroelements** are known to be essential for human nutrition; they are required in more than 100 mg per day. **Trace elements** or **microelements** (e.g. iron, iodine, zinc, manganese, cobalt, copper, molybdenum, etc.) are required in very small amounts. Altogether 20 vitamins are thought to be required in small amount in human nutrition. The major types of food relative to their nature of nutrients and basic functions are shown in Table 5.1.

Table 5.1 : Types of Food Relative to their Nature of Nutrients and Basic Functions

Major Food	Nutrient	Function
	Carbohydrates	
Sugar, glucose, sugarcane, honey and milk	Sugars	
Wheat, bread, maize, corn, rice and potatoes	Starch	
	Lipids	**Energetic**
Butter, lard, sunflower oil, seeds and vegetable oils, nuts, almonds, cheese, liver oils and egg-yolk	Fats and oil	
	Proteins	
Flesh (meat, chicken, fish), milk, pulses, cereals, egg (albumen and yolk) and cheese	Amino acids	
	Minerals	
Table salts, pickles and butter	Sodium	
Table salts, pickles and butter	Chlorine	
Jaggary, banana, date and potato	Potassium	
Milk, cheese, curd, fish, eggs, pulses, carrot, cabbage and dark green leaves	Calcium	**Constructive**
Meat, fish, milk, cheese, egg, pulses and cereals	Phosphorus	
Meat, liver, egg-yolk, fish, green leaves, nuts, fig, and pulses	Iron	
Sea-fish, sea-weed, onion and iodised table salt	Iodine	
	Vitamins	
Cod and shark liver oil, liver, kidneys, egg-yolk, green and yellow vegetables (carrot, mango, lettuce, cabbage), tomato, yeast, milk and butter	A (Retinol)	
Whole cereals, dried beans, pork meat, egg-yolk, yeast	B1 (Thiamine)	
Meat, liver, fish, milk, egg, cheese, legumes and green leafy vegetables	B2 (Riboflavin)	
Pulses, cereals, meat, liver,fish, intestinal bacteria and yeast (Also synthesised in the human body from the amino acid, tryptophan)	PP (Pellagra preventing or nicotinamide)	**Protective**
Citrus fruits, vegetables, tomato, and peppers	C (Ascorbic acid)	
Cod and shark liver oil, chicken, egg-yolk, milk, butter, etc. (Also synthesised in human skin in presence of sunlight)	D (Calciferol)	

5.2 Modes of Nutrition in Animals

Based on the methods of procurement or collection of food, heterotrophic nutrition is classed into four major types of nutrition. These are : holozoic, saprozoic, parasitic and symbiotic. Nutrition involving engulfment of the whole or part of a plant or an animal, either in solid or in liquid state, is called animal-like or **holozoic nutrition** (e.g. most of the free-living protozoans and animals). A few animals (e.g. spiders, house-fly, etc.) do not ingest solid food. Instead, they secrete digestive enzymes directly onto their food, which usually are dead or decaying matters, and then suck the food digested outside the body. This is called

saprozoic nutrition. Parasites thrive on liquid food material obtained from the body of the host, and their mode of nutrition is designated as **parasitic nutrition** (e.g. *Plasmodium*, *Trypanosoma*, *Taenia* and *Ascaris*). Often, two organisms or animals might live in association and derive nutrition from each other. This is the case with some symbionts whose nutrition is referred to as **symbiotic nutrition** or **mutualism**. For example, *Escherichia coli* that lives in the intestine of man synthesises vitamin B_{12}, which is used by man and the *E. coli* receives, in return, simpler food from the intestine of man.

Types of Holozoic Nutrition

Based on their food habits, holozoic animals are broadly classified into three categories: herbivores, carnivores and omnivores. Those consuming only algae or plant materials are called **herbivores** (e.g. cow, horse and rabbit). Flesh-eating animals (e.g. lion, tiger and dog) are called **carnivores**, whereas animals that eat both plants and other animals (e.g. cockroach, rat, bear, crow, man, etc.) are considered as **omnivores**. Besides, many other variations can be found. For example, toads, lizards and spiny ant-eaters are **insectivores** (insect eaters), monkeys, birds and bats are **frugivores** (fruit eaters), female mosquito (*Anopheles*), leeches and vampire bats are **sanguinivores** (feed on blood of vertebrates), earthworms are **detritivores** (feed on decaying organic matter), and butterflies and male mosquitoes are **fluid feeders** (feed on fluids from plants).

Steps of Holozoic Nutrition

Holozoic nutrition involves four steps. These are: ingestion, digestion, absorption and egestion. **Ingestion** is the method of feeding. Animals are variously adapted, both internally and externally, for ingestion of the specific type of food they take in. Depending upon the gross size of food, feeding in animals may be classified into two categories : **microphagy** (feeding on microscopic organisms, e.g. *Amoeba*, *Paramoecium*) and **macrophagy** (feeding on larger forms of organisms, e.g. majority of non-chordates and some chordates). **Digestion** is the breaking down of the organic food molecules (carbohydrates, lipids, proteins and nucleic acids). It involves the chemical process of hydrolysis, and the simpler and smaller molecules thus produced can then get entry into the surrounding cells. Generally, two major types of digestion are encountered in the heterotrophs : **intracellular digestion** and **extracellular digestion**. *Amoeba* digests its prey inside the food vacuole (phagocytic vesicle) and expels the undigested food by **exocytosis.** Such a type of digestion is called **intracellular digestion** (e.g. sponges). More organised animals, like cnidarians (e.g. *Hydra*, *Aurelia*, etc.), have developed sac-like coelenteron or **gastrovascular cavity** (Fig. 5.1), which is lined by various types of endoderm cells. Gland cells of the endoderm secrete their enzymes into the cavity and digest the food extracellularly. This kind of digestion outside cells within a cavity is **extracellular digestion**. However, in cnidarians, as soon as the food is reduced to small fragments, the nutritive cells ingest them and complete the process of

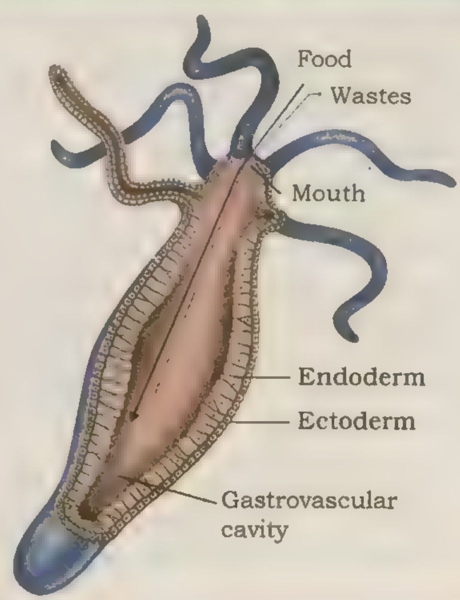


Fig. 5.1 Longitudinal section of Hydra showing gastrovascular cavity

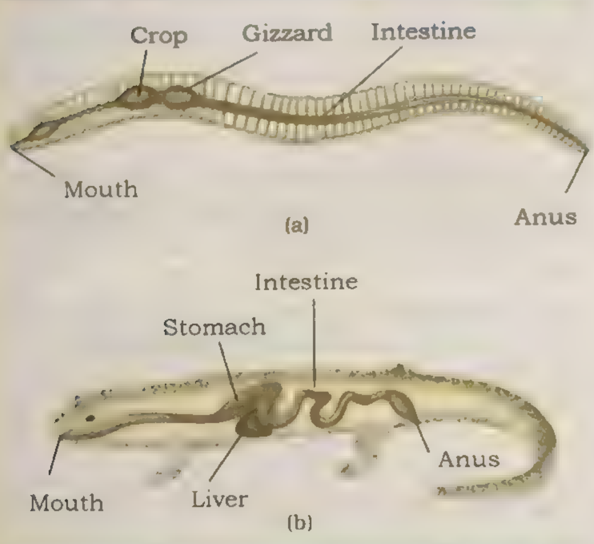


***Fig. 5.2** Complete digestive tracts in (a) Earthworm, and (b) Salamander*

digestion intracellularly. Also, the free-living platyhelminths (e.g. *Planaria*) employ both types of digestion.

With more advancement in the organisation, most non-chordates and chordates have developed a **complete digestive tract** with two openings (Fig. 5.2). They use the more efficient tube-within-a-tube plan for digestion. Incoming food enters through the mouth and undigested food is eliminated through the anus. These animals have resorted to a much efficient digestive system and extracellular digestion. The entire alimentary canal, and its associated glands, together constitute **alimentary** or **digestive system**. The digested food is then **absorbed** within the cytoplasm of cells or through the cells lining the alimentary cavity. Protozoans circulate the digested food by cytoplasmic streaming. Animals with definite digestive tract have developed a blood vascular system for circulation of the absorbed food substances to different constituent cells of the body. These absorbed food molecules are then used for construction of their own molecules or body substances. Some parts of the food remain unutilised due to the inability of digestion. The animal, then, egests or eliminates the undigested food. Protozoans eliminate their undigested food from the food vacuole; cnidarians remove the undigested food through the single opening leading to the gastrovascular cavity, whereas most non-chordates and chordates use the anus for elimination of undigested food in the form of faeces.

5.3 Digestive System of Cockroach

The digestive system of cockroach, *Periplaneta americana*, consists of alimentary canal and digestive glands (Fig. 5.3). You have studied the digestive system of another insect in your earlier classes.

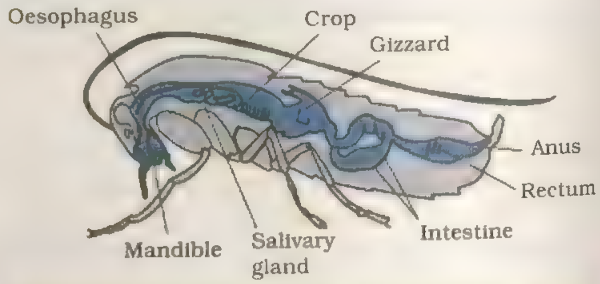


***Fig. 5.3** Digestive system of cockroach*

Cockroaches are omnivorous and devour any kind of organic molecule as food. The ingested food is cut into pieces by the **mandibles** and passed into the **buccal cavity**, where it mixes with the **saliva**. Ultimately the food enters into the **crop**, where it is stored and gradually transferred into the **gizzard**. Six chitinous and circular teeth present in the gizzard mince the food. The hairy cushion allows the fine particles of food to go into the mid gut. Various digestive **enzymes**, like amylase, maltase, lactase, lipase, protease, etc., are secreted from the lining cells of the **midgut** and **hepatic caeca**. Bacteria present in the mid gut synthesise cellulase. All these enzymes **digest** (hydrolyse) and break the complex organic molecules into simpler forms, which are mostly

absorbed in the midgut. The lining cells of the caeca absorb the glucose only. Undigested food, then, passes to the hindgut. Here, water and mineral salts are absorbed. The undigested food is finally **egested** through the anus.

5.4 Digestive System of Humans

Digestive system of man consists of alimentary canal or gut and some accessory digestive organs (Fig. 5.4).

The Alimentary Canal

It is a coiled, muscular tube extending from the mouth to the anus. It is about 6-9 metres long and consists of many specialised sections. Arranged sequentially, these are mouth, oral cavity, pharynx, oesophagus, stomach, small intestine, large intestine, rectum and anus. Also, some accessory digestive organs, like salivary glands, pancreas, liver and gall bladder (biliary system) are connected to the main system by a series of ducts.

The **mouth** is an opening and is protected by upper and lower lips (labia). It leads into the **oral cavity** that has two lateral walls (cheeks), an anterior roof (hard palate), a posterior roof (soft palate) and a pair of jaws, (upper maxilla and lower mandible). Each half of the jaws holds four types of **teeth**. Thus, human teeth are dissimilar, or **heterodont**. 2 **incisors**, which are chisel shaped and used for cutting, chopping or gnawing; 1 **canine**, which is more pointed and used for ripping or shredding; 2 **premolars** and 3 **molars** (cheek teeth), which are broad and used for shearing, crushing and grinding.

The **dental formula** (arrangement of teeth) of humans is represented as I $^2/_2$, C $^1/_1$, Pm $^2/_2$, M $^3/_3$. Each **tooth** has three layers, namely crown, neck and root (Fig 5.5). Crown remains capped with hard **enamel**, formed principally of calcium phosphate; it forms the chewing surface of the tooth. Both crown and root are covered by a layer of bony **dentine** inside which is a central **pulp** having nerve and blood supplies. As neck and root are held in a socket of cement, human teeth are regarded as **thecodont**. Human teeth are also called **diphyodont** because the milk teeth are replaced by permanent teeth in the adult. The oral cavity also receives saliva through the ducts of the salivary glands.

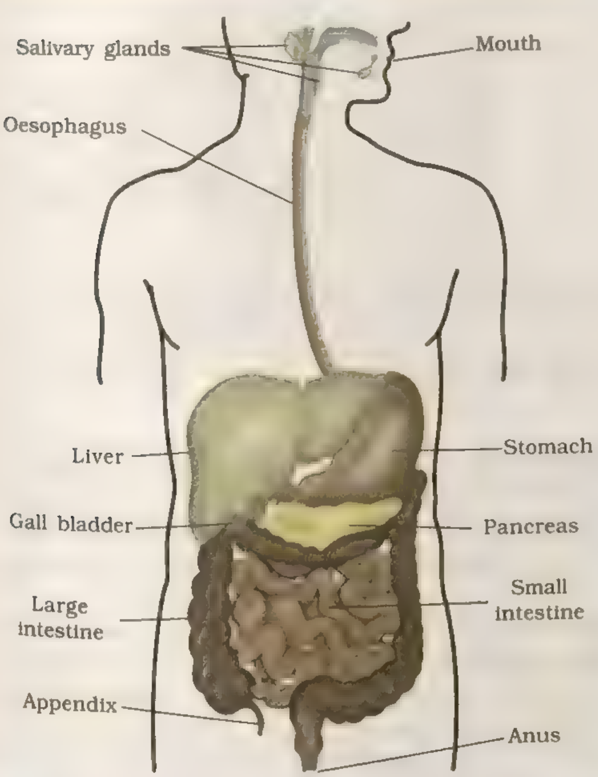


Fig. 5.4 *Human digestive system*

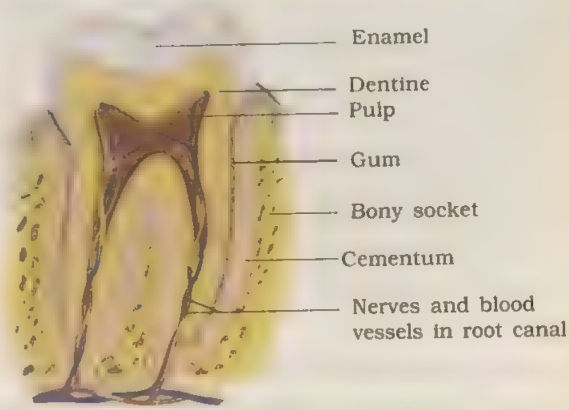


Fig. 5.5 *Structure of a human premolar tooth*

The oral cavity leads through the **pharynx** into the tube-like **oesophagus** (food tube), which runs downward through the throat and thorax. A structure called the **epiglottis** guards the opening of the trachea (windpipe). The oesophagus invades the **diaphragm**, a muscular transverse partition that separates thorax from abdomen, and leads into the stomach. A ring of muscle, the **oesophageal sphincter**, controls the opening of oesophagus into the stomach. The **stomach** is a large muscular Ɔ-shaped sac and located on left side in the upper portion of the abdominal cavity. It has three regions, **fundus** (upper part), **body** (middle part) and **pylorus** or **antrum** (lower part). Pylorus is guarded by sphincter muscles and opens into the first section of the **small intestine**, called the **duodenum**, which is U-shaped. The common **bile duct** opens into the duodenum and drains into it juices from pancreas and liver. The duodenum leads into **jejunum**, which is also a bit coiled and longer. The last part of the small intestine, the **ileum**, is much longer (about 7 m long and 2-3 cm in diameter in adult man) and more coiled. It occupies the lower part of the abdominal cavity.

The small intestine leads into a much shorter **large intestine** or **colon**. It is called 'large' because of its larger diameter. At the juncture where small intestine opens into the colon, a small and blind sac, the **caecum**, is present. It is very small and plays no role in nutrient absorption. It is a vestigial organ. A small finger-like projection emerges from the top of the caecum. It is known as **appendix**. In humans, the large intestine ascends from the caecum as the **ascending colon**, then crosses to the left side as the **transverse colon**, and descends again as the **descending colon**. The colon empties into the last part of the intestine, the **rectum**, which is a storage chamber for faeces.

Histology of Human Gut

Four major layers of different cell types form the wall of the alimentary canal. Starting in its cavity or **lumen**, the innermost layer is the **mucosa** (moist and friction resistant lining epithelium), which contains the secretory and absorptive cells. At the base of the mucosa are some smooth cells. Just outside the mucosa is the **submucosa** (soft connective tissue layer with blood and lymph vessels and nerve supply). External to the submucosa is the **muscularis externa**, which is formed of a circular inner layer and a longitudinal outer layer of smooth muscle. The outermost layer of the gut is a fibrous coat, called the **serosa**. The mucosa is produced into millions of microscopic folds or finger-like projections, called **villi**

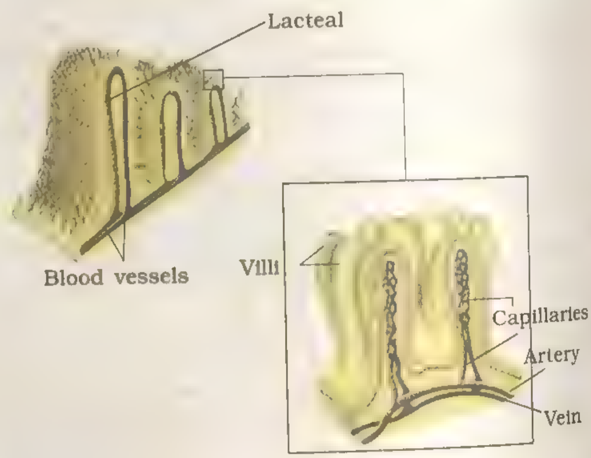


Fig. 5.6 *Portion of mucosa of the intestinal wall showing villi*

(Fig. 5.6). These villi are supplied with a network of blood capillaries and also a network of lymph vessels, the largest of which is the central **lacteal**. Besides, the cells that line the surface of the villi, produce numerous microscopic bristle-like projections, called the **microvilli** or **brush border**. These further increase an enormous surface area for the absorption of the nutrients. On the surface of the mucosal epithelium are billions of single-cell mucous glands, called **mucous** or **goblet cells**. These cells mainly secrete mucus that acts as a lubricant and protects

the epithelial surface from excoriation and digestion. Many surface areas of the gastrointestinal tract are lined by invaginations of the epithelium (pits) into the submucosa. These pits of the intestine are called **crypts of Leiberkûhn**. These crypts contain specialised secretory cells. Besides, the stomach and upper duodenum contain many deep **tubular glands**.

The Accessory Digestive Organs

Human digestive system has many accessory organs. Of these, the **tongue**, which is located in the buccal cavity, is a muscular organ with bony attachments (styloid process and hyoid bone) with the floor of buccal cavity. Tongue is provided with gustatory receptors, called the **taste buds**. The accessory digestive glands include the salivary glands, the liver and the

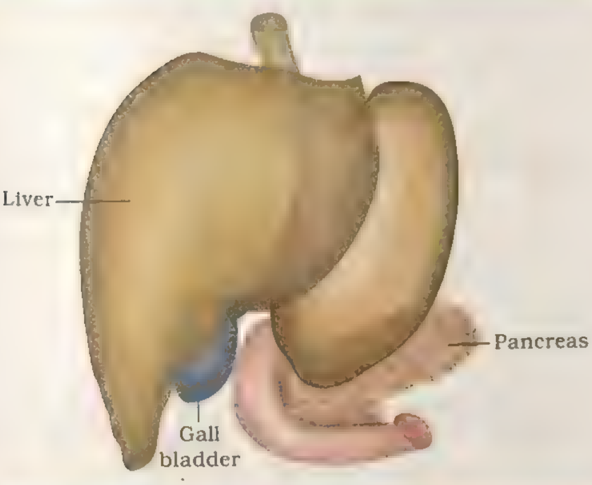


Fig. 5.7 *Relative sizes and positions of liver, gall bladder and pancreas*

gall bladder and the pancreas. Humans have three pairs of **salivary glands** – parotid glands in the cheek, submandibular and sublingual, opening into the floor of the mouth. **Liver** is situated in the right upper part of the abdomen, just below the diaphragm. In an adult human, the liver weighs about 1.5 kilograms. The **gall bladder** is a small and

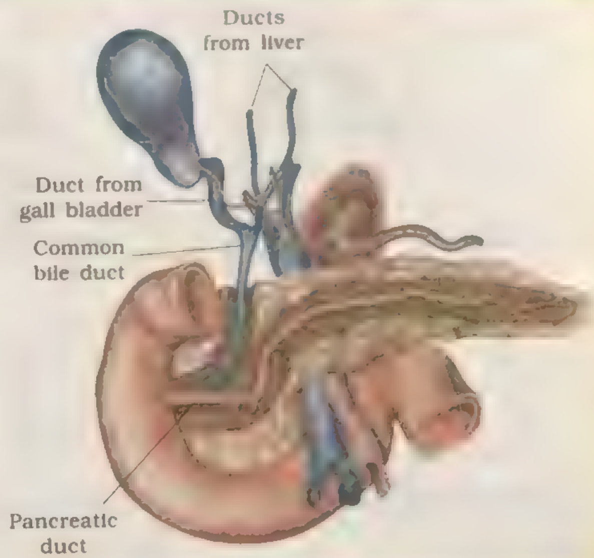


Fig. 5.8 *The duct systems of liver, gall bladder and pancreas*

elongated muscular sac situated below the liver. The **pancreas** is an elongated gland that is situated near the junction of the stomach and the duodenum. Both the liver and pancreas act as **glands**, whereas the gall bladder acts as a **storing organ**. The relative sizes and positions of liver, gall bladder and pancreas are shown in Figure 5.7. The duct systems of these three glands are depicted in Figure 5.8.

Mobility of Human Gut

The ability of the alimentary canal to contract is called **mobility**. For digestion, absorption and subsequent defecation, the food has to be propelled sequentially along the entire length of the alimentary canal. In each of these sections, the food is subjected to different kinds of actions and fates. The food is tasted in the oral cavity and mixed with **saliva**, which is a mixture of water and electrolytes (Na^+, K^+, Cl^-, HCO_3^-), derived from the blood plasma, mucus and serous fluids, salivary amylase or ptyalin (enzyme) and lysozyme (antibacterial agent), all secreted by the salivary glands. Tongue manipulates food during chewing and mixing

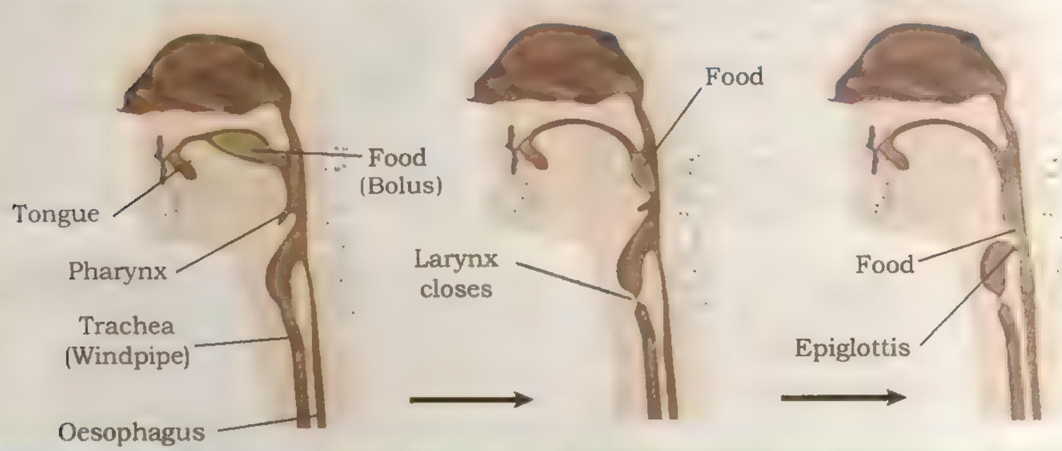


Fig. 5.9 Swallowing of food

with saliva. This collection of food, the **bolus,** is then pushed inward through the pharynx into the oesophagus. This process is referred to as **swallowing** (Fig. 5.9). Swallowing involves coordinated activity of tongue, soft palate, pharynx, and oesophagus. The tongue blocks the mouth, soft palate closes off the nose, and the larynx rises, so that the epiglottis closes off the trachea. As pharynx is also a part of the respiratory system, the openings of the nasal passage and trachea (windpipe) are closed off by reflex action during swallowing. However, the first (buccal) phase is voluntary. Food, thus, moves into the pharynx and passes downward into the oesophagus. A travelling wave of constrictions, called **peristalsis**, pushes the luminal contents (food) downward (Fig. 5.10). Peristalsis is produced by involuntary contraction of circular muscles, which is preceded by a simultaneous contraction of the longitudinal muscle, and relaxation of the circular muscle lining the gut. When a peristaltic wave reaches the end of the oesophagus, the sphincter opens, allowing the passage of bolus food to the stomach. The sphincter muscle, guarding the junction of the oesophagus and stomach, normally remains closed and does not allow contents of the stomach to move back.

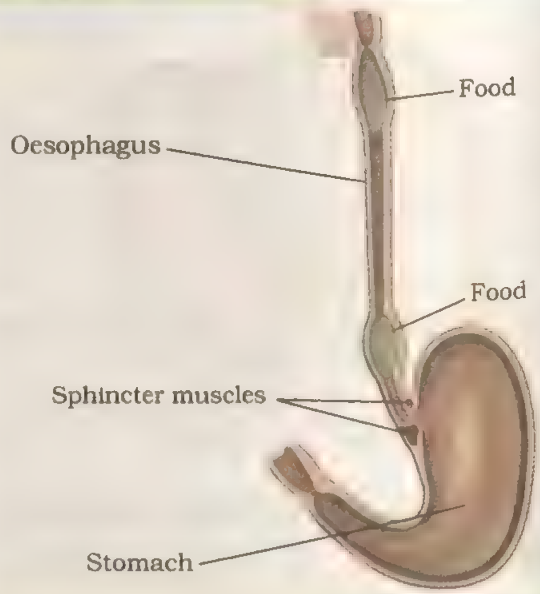


Fig. 5.10 Peristaltic movement of food in oesophagus

Gastrointestinal Secretions and Digestion

The exocrine tissues include the salivary glands, the secretory cells in the stomach and intestinal epithelium, and the secretory cells of the liver and pancreas. Exocrine secretions

usually consist of aqueous mixtures of substances, like water, ions, mucus and enzymes. Humans perform extracellular digestion with the aid of a group of enzymes, called **hydrolases**, released from the cells of the digestive system.

Enzymatic **hydrolysis** is initiated in the oral cavity by the action of starch-digesting enzyme, **ptyalin** or **α-amylase**. This enzyme, secreted by the salivary glands, helps in the breakdown of starch into disaccharide (maltose). Mucus of the saliva moistens and dissolves some of the food and lubricates the oesophagus. **Bicarbonate ions** in saliva neutralise the acids in food. The thiocyanate ions of saliva act as antimicrobial agent, and prevent infection by the microbes that often enter along with food. About 30 per cent of starch is hydrolysed in the mouth. Carbohydrate digestion continues in the bolus as it passes to the stomach.

Initially, the stomach stores food, and supplements the action of teeth by churning and breaking up larger pieces of food with its muscular contraction. In the stomach, the food is exposed to the action of **gastric juice**, which is a mixture of hydrochloric acid, the enzyme pepsinogen and mucus. The **goblet cells**, present in the mucous epithelium of stomach, mainly secrete mucus, which acts as a lubricant and protects the epithelial surface from excoriation by HCl and digestion by pepsin. The **parietal cells** or **oxyntic cells**, located in the stomach's gastric pits, mainly secrete hydrochloric acid and intrinsic factor. The **peptic cells**, or **chief cells**, or **zymogenic cells**, secrete large quantity of pepsinogen. Both type of cells are part of the **oxyntic tubular glands** of the stomach epithelium. The **pyloric tubular glands** of the stomach secrete mainly mucus, some pepsinogen and the hormone gastrin. **Hydrochloric acid** inactivates the salivary amylase and prevents further breakdown of carbohydrate (disaccharides); also, it kills micro-organisms and lowers the pH of the stomach between 1.5 and 2.5 (very acidic). **Pepsinogen** has no proteolytic activity. Actually, pepsinogen is the inactive precursor of pepsin and is considered as **proenzyme** or **zymogen**, and normally does not pose any threat to the stomach. After exposure to hydrochloric acid, pepsinogen turns into **pepsin**, which is the principal **protease** (proteolytic enzyme) of the stomach and digests proteins into peptides. It is inactivated when it comes in contact with the mucus. Bicarbonate ions reduce acidity near the cells lining the stomach. Partially digested broth of food then leaves the stomach through its pyloric end and enters the duodenum as a **chyme**.

The duodenum also receives digestive enzymes and bicarbonates from the pancreas, and bile from the liver via gall bladder. Trypsin, chymotrypsin and carboxypeptidase are proenzymes (zymogens), and are secreted in their inactive forms as **trypsinogen**, **chymotrypsinogen** and **procarboxypolypeptidase**, respectively. Pancreatic acinar cells (exocrine part of pancreas) produce **pancreatic juice** that contains protein-digesting enzymes, namely **trypsin**, **chymotrypsin** and **carboxypeptidase**, and **carbohydrases** (carbohydrate digesting enzymes), like **pancreatic α-amylase**. All these enzymes enter the duodenum via the pancreatic duct. Trypsinogen is activated by enterokinase secreted by the intestinal mucosa, whereas chymotrypsinogen and procarboxypolypeptidase are activated by trypsin. Pancreatic juice also contains **bicarbonate** and **water**, which are secreted by the ductules and ducts of the **acinar cells** of the pancreas. Bicarbonate neutralises hydrochloric acid of the chyme that has entered the duodenum. Bile, the main exocrine secretion of liver, is initially concentrated and stored in the gall bladder. On stimulation, bile is squeezed into the duodenum through the cystic and common bile duct. **Bile** is a watery greenish fluid mixture containing bile pigments, bile salts, cholesterol and phospholipids. The **bile salts** play a very important role in the digestion of fats. As the fats are insoluble in water, they enter the intestine as drops within the watery chyme. The bile salts, which are partly lipid-soluble and partly water-soluble, emulsify the fat particles and, as a result, the fat-drops acquire a greater surface area. The enzyme lipase, then acts

upon fat-drops and allows its digestion into glycerol and fatty acids. **Bile pigments** are the products of dead erythrocytes, mainly biliverdin and bilirubin (the non-iron end products of breakdown of haemoglobin) that has spilled into the blood plasma. The body later excretes these substances and excess of cholesterol along with faeces. In response to the action of stimuli received from the **vagus** (X cranial) **nerve** and **secretin** (a gastrointestinal hormone), the **Brunner's gland** (compound tubular gland of the duodenal epithelium) secretes, a large amount of viscous, enzyme-free, alkaline and watery **mucoid fluid**. This secretion enables the duodenum to withstand the acidic chymes

Table 5.2 : An Overview of the Action of Major Enzymes in Humans

Enzyme	Site of Action	Substrate	Products of Action
Salivary Juice (Salivary Gland)			
Salivary amylase or Ptyalin	Mouth and Stomach	Starch	Disaccharides
Gastric Juice (Stomach)			
(a) Pepsinogen : pepsin	Stomach	Proteins	Large peptides
Pancreatic Juice (Pancreas)			
(a) Pancreatic α-amylase (Duodenum)	Small intestine	Starch/ Glycogen	Disaccharides
(b) Trypsinogen : trypsin	do	Proteins	Large peptides
(c) Chymotrypsin	do	Proteins	Large peptides
(d) Elastase	do	Elastin	Large peptides
(e) Carboxypeptidases	do	Large peptides	Oligopeptides
(f) Aminopeptidase	do	Large peptides	Oligopeptides
(g) Lipase	do	Triglycerides	Monoglycerides fatty acids, glycerol
(h) Nucleases	do	Nucleic acids	Nucleotides
Intestinal Juice (Small Intestine)			
a) Enteropeptidase or enterokinase	Duodenum	Trypsinogen	Trypsin
b) Peptidase	do	Oligopeptides	Amino acids
c) Disaccharidases	do	Disaccharides	Monosaccharides
d) Nucleotidase	do	Nucleotides	Nucleosides phosphoric acid
e) Nucleosidases	do	Nucleosides	Sugars, purines pyrimidines

entering from the stomach, until it is neutralised by the alkaline pancreatic and biliary secretions. The mucus is secreted by the **goblet cells**, whereas water and electrolytes are secreted by the **enterocytes** present on the intestinal crypts. The mucus protects the duodenal wall from getting digested. The excess of bicarbonate ions present in the secretion of Brunner's gland combines with the bicarbonate ions of the pancreatic juice, and becomes a part of **intestinal juice**, or **succus entericus**. become a part of Digestion of most of the nutrients takes place in the duodenum under the action of various enzymes. An overview of the action of major enzymes in the digestion of food in humans is represented in Table 5.2.

5.5 Hormonal Control of Digestion in Humans

The activities of **gastrointestinal (GI) tract** are coordinated by **nervous** and **endocrine systems** of the body. The very sight and smell of food primarily stimulates the nervous system. These visual and odorous stimuli induce the salivary gland and stomach to release their hormones. The role of some of the major **gastrointestinal peptide hormones** in human digestion is summarised in Table 5.3.

5.6 Absorption and Assimilation of Digested Products in Humans

After the conversion of large food molecules into smaller forms, the breakdown products are transported from the gut to different tissues and cells. Digestion products are absorbed mainly through the microvilli of the apical membrane of the absorptive epithelial cells that are present on the wall of the small intestine (Fig. 5.11). The capillary beds of the intestinal villi pick up the products of digestion. **Simple (passive) diffusion** of small and water-soluble molecules occurs via concentration gradient across apical membrane of the brush border of the cells lining the intestinal villi. These include fatty acids, monoglycerides, cholesterol and other fat-soluble substances (Fig. 5.11).

Table 5.3 : Role of Some Major Gastrointestinal Peptide Hormones in Digestion

Hormone	Source Secretion	Stimulus	Target/Action
Gastrin	Pyloric stomach	Vagus nerve activity; peptides and proteins in stomach.	Secretory cells and muscles of stomach; secretion of HCl and stimulation of gastric mobility.
Cholecystokinin (CCK)	Upper small intestine (Duodenum)	Food (fat rich chyme and amino acids) in duodenum.	Gall bladder; contraction of gall bladder (bile release).
Secretin	Intestinal wall (Duodenum)	Food and strong acid in stomach and intestine.	Pancreas, secretory cells and muscles of stomach; secretion of water and bicarbonate ($NaHCO_3$); inhibition of gastric motility.
Gastric Inhibitory Peptide (GIP)	Upper small intestine (Duodenum)	Monosaccharides and fats (fatty chyme) in duodenum.	Gastric mucosa and muscles; inhibition of gastric secretion and motility (slowing food passage).

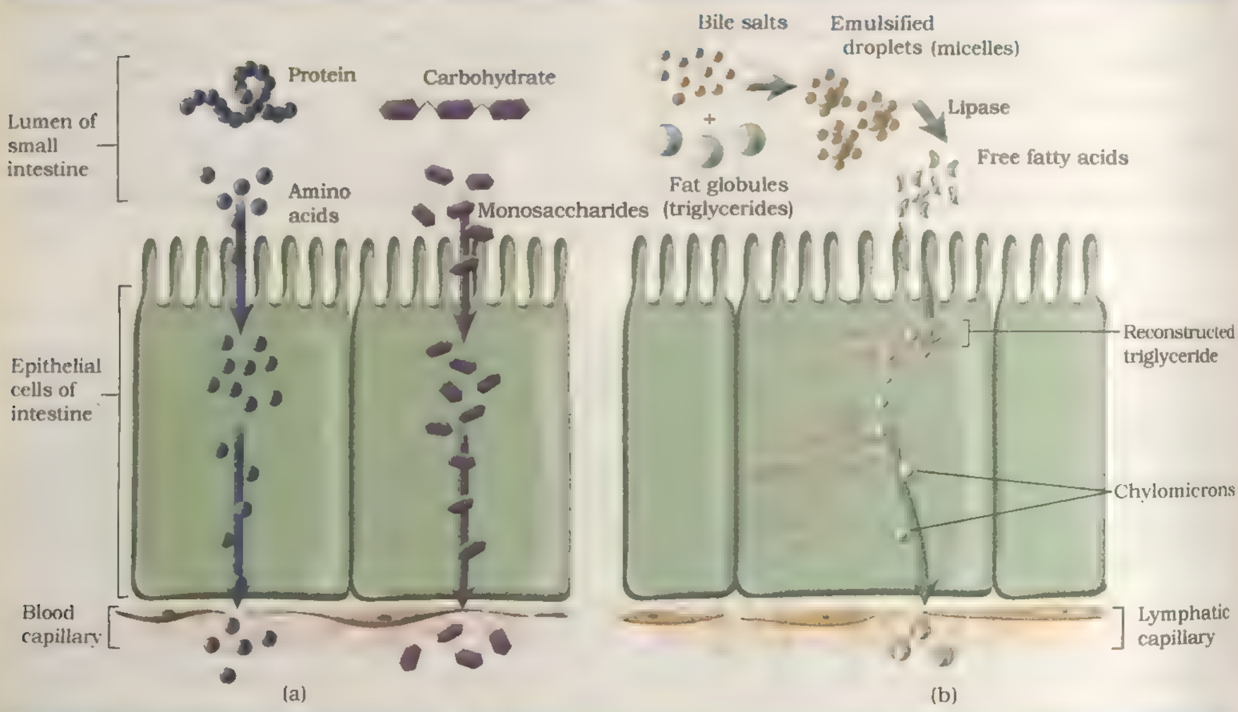


Fig. 5.11 *Absorption of digested food (a) Amino acids and monosaccharides, and (b) Fatty acids*

Water and water-soluble substances (nutrients) are absorbed by osmosis into the intestinal cells, and thence, to blood. Hydrophilic lipid-insoluble sugars, such as fructose, are carried down their concentration gradient by **facilitated diffusion**, which is facilitated by specific transporter proteins present in the absorptive cell membrane. This process is powered by coupling sugar transport to the electrochemical gradient for Na^+ across the brush border. In **active transport**, entry of nutrients, like amino acids, occurs via co-transport channels, which couple the movement of Na^+ down a electrochemical gradient. The energy required for active transport is derived from hydrolysis of ATP by the carrier protein acting as ATPase. From the capillaries, the nutrients enter the liver circulation, and thus, the simple forms of food pass to different cells and tissues of the body. The cells and tissues use these raw materials for their constructive purpose. The water-insoluble monoglycerides, fatty acids and glycerol, are first incorporated into water-soluble droplets, called **micelles** (a combination of fatty acids, monoacylglycerols and bile salts). From these micelles, fatty acids, glycerols, sterols, and fat-soluble vitamins are absorbed by facilitated diffusion through the brush border membrane, and are reconstructed within the absorptive cells into triglycerides. The remnant of the micelles is left behind and combines with new fatty acids and monoacylglycerols. The intestinal absorptive cells then, collect the reconstructed triglycerides, combine them with phospholipids and cholesterol, and release into the lymphatic capillary in the form of protein-coated water-soluble fat globules or droplets, called the **chylomicrons**. These are about 150 μm in diameter. These droplets are then, transported to blood via the central **lacteal** of the lymphatic system for distribution throughout the body. It should be remembered that most of the nutrients are absorbed before the chyme reaches the large intestine.

5.7 Egestion

Peristalsis gradually pushes the slurry of indigestible materials of the small intestine into the large intestine or colon. Approximately, 1500 ml of chyme normally passes into the large intestine each day. The colon absorbs most of the water, electrolytes and ions from these contents. This is accomplished by active pumping of sodium and water by osmosis from the chyme. The other function of colon is to help in the excretion of excess salts from the blood. The population of *Escherichia coli* (bacterium), which is a resident species of the colon, lives on this undigested matter. This bacterium, in turn, produces vitamin B_{12}, vitamin K, thiamin, and riboflavin that are absorbed across the wall of the colon. Later on, the chyme is slowly solidified into coherent faeces, which are about three-fourth water and one-fourth solid matter consisting of about 30 per cent dead bacteria, 10 to 20 per cent fat, 2 to 3 per cent protein and 30 per cent undigested roughage and dry constituents of digestive juices. Faeces are given out through the anus by the process of defecation or **egestion**.

5.8 Nutritional Requirements of Humans

As mentioned earlier, carbohydrates, lipids and proteins serve the energy sources, whereas minerals, vitamins and water are non-provider of energy Table 5.1. Now, let us know about the overall requirements and use of nutrients in humans.

Energy Yielding Nutrients

Carbohydrates are used primarily as sources of chemical energy, to be either metabolised immediately as glucose, or stored as glycogen. The synthesis of glycogen is called **glycogenesis**. The liver can store enough glycogen to maintain blood glucose level for several hours. Under acute starved conditions, the liver cells begin to convert amino acids and the glycerol (digestive products of fat molecules) into glucose. Such production of new glucose is known as **gluconeogenesis**. Proteins are used as structural components of tissues, as channels, transporters, regulatory molecules and enzymes. However, proteins can also be utilised as energy sources, when broken down to amino acids. Out of the 22 amino acids identified so far as the constituents of proteins, 8 (10 in children) cannot be synthesised in human body. These must be provided in the diet from outside and are designated as **essential amino acids**. Lipid (fat) molecules are especially suitable as concentrated energy reserves. The fat cell of adipose tissue can store up to 95% of their volume of triglycerides, and for this reason adipose tissues are often called the **fat depot** of body. Triglycerides are used as **fuel**. Human body is able to synthesise most of the lipids in enough quantity, except three polyunsaturated fatty acids such as linoleic, linolenic and arachidonic acids. These **essential fatty acids** must be provided to the human body through diets.

The calorific value : The energy requirements of animals, and the energy content of food, are expressed in terms of a measure of heat energy because heat is the ultimate form of all energies. This is often measured to as **calorie** (cal) or **joule** (J), which is the amount of heat energy required to raise the temperature of 1 g of water by 1° C. Since this value is a tiny amount of energy, physiologists commonly use **kilocalorie** (kcal) as a unit of measure (1 kcal = 1,000 calories) or **kilojoule** (kJ). One kilocalorie is the amount of energy required to raise the temperature of 1 kg of water through 1^0 C. Nutritionists, traditionally refer to kcal as the **Calorie** or **Joule** (always capitalised). The amount of heat liberated from complete combustion of 1 g food in a bomb calorimeter (a closed metal chamber filled with O_2) is its **gross calorific** or **gross energy value**. The actual amount of energy liberated in the human body due to combustion of 1 g of food is the **physiologic value** of food. Gross calorific values of carbohydrates, proteins and fats are 4.1kcal/g, 5.65 kcal/g and 9.45 kcal/g, respectively, whereas their physiologic values are 4.0 kcal/g, 4.0 kcal/g and 9.0 kcal/g, respectively.

Minerals and Vitamins

Both minerals and vitamins occur as small molecules and mostly, do not require digestion.

Table 5.4 : Some Important Minerals and their Functions

Mineral	Functions
Calcium	Component of bone and teeth; essential for normal blood clotting; needed for normal muscle and nerve function.
Chlorine	Principal anion of interstitial fluid; important in fluid and acid-base balance.
Copper	Component of enzymes for melanin synthesis; essential for haemoglobin synthesis.
Iodine	Component of thyroid hormones. Its deficiency produces goitre.
Iron	Components of respiratory pigments (like haemoglobin and myoglobin), respiratory enzymes (like cytochromes) and oxygen transport enzymes. Its deficiency causes anaemia.
Phosphorus	Important structural component of bones, DNA and RNA; essential in energy transfer, storage of energy (ATP) and other metabolic activities; maintains normal blood pH (buffer action).
Potassium	Principal cation in the cytoplasm; controls nerve excitability and muscle contraction.
Sodium	Principal cation of interstitial fluid; maintains fluid balance; essential for conduction of nerve impulse.
Sulphur	Components of protein and peptide hormones (e.g. insulin); necessary for normal metabolism.
Zinc	Component of at least 70 enzymes, like carbonic anhydrase, and some peptidases.

Table 5.5 : Some Important Vitamins and their Functions

Vitamin	Functions
Fat-soluble	
Calciferol (D)	Absorption of Ca^{2+} from small intestine, needed for growth and maintenance of bone (synthesised in human skin in presence of sunlight).
K	Essential for coagulation of blood (produced by intestinal bacteria).
Retinol (A)	Principal component of retinal pigments; promotes normal vision, growth of bones and teeth and maintenance of epithelial tissue.
Tocopherol (E)	Inhibits oxidation of unsaturated fatty acids and vitamin A.

	Water-soluble
Ascorbic Acid (C)	Synthesis of collagen, bone matrix, tooth dentine and other extracellular materials, metabolism of many amino acids; helps body to withstand injury from burns and toxicity and acts as antioxidant.
Cyanocobalamin (B_{12})	Important for nucleoprotein synthesis and formation of RBC (produced by intestinal bacteria).
Biotin	Coenzyme needed for protein and fatty acid synthesis.
Folic Acid (folacin, pteroglutamic acid)	Coenzyme needed for nucleoprotein synthesis and formation of RBC.
Niacin (nicotinic acid)	Coenzyme in hydrogen transport (NAD, NADP).
Pantothenic Acid	Component of coenzyme A (CoA).
Pyridoxine (B_6)	Coenzyme for amino acid and fatty acid metabolism.
Riboflavin (B_2)	Flavoproteins in oxidative phosphorylation.
Thiamine (B_1)	Formation of carboxylase enzyme involved in decarboxylation (citric acid cycle).

Minerals are ingested as salts dissolved in water, or as part of food. Still, a few of the minerals are absorbed with the aid of digestive juices (like bile) and gastric juices. Of the twenty-one essential minerals required by man, some are important for maintaining fluid balance, whereas others help to regulate metabolism by acting as a component of enzymes. **Vitamins** are essential for normal metabolism, growth and sound health. Humans can synthesise vitamin A (retinol) with the help of plant pigment, carotene, which is available in yellow and green leafy vegetables. Vitamin A forms retinal pigment of human eyes, such as rhodopsin of rod cells and iodopsin of cone cells. Humans can also synthesise vitamin D (calciferol) in their skin in presence of ultra-violet rays of sunlight. Although most animals can synthesise vitamin C from glucose, humans cannot; hence, they require it in their diet. Tables 5.4 and 5.5 list some of the important minerals and vitamins and their respective role in human nutrition.

5.9 Nutritional Deficiencies and Disorders

Deficiencies of nutrients, like vitamins, minerals and proteins, in the food are related to specific disorders, diseases and abnormalities in humans. This relationship is summarised in Table 5.6.

Impairment of health due to improper intake of food or nutrients, results in the effect recognised as **malnutrition**. Malnutrition is a term which covers problems of both undernutrition and overnutrition. An individual or a group of individuals, may be undernourished due to non-availability of food, leading to deficiency of minimum required food and nutrients. In this situation of **undernutrition**, the intake of food is too insufficient to meet the needs for metabolic energy. Consequently, the individual shall have to make up the shortfall by metabolising some molecules of its own body. Excess intake of food and nutrients may cause a great deal of harm to the body. The excess nutrients are stored as increased

Table 5.6 : Nutritional Disorders due to Deficiency of Dietary Component

Nutrient	Name of Deficiency	Deficiency Symptoms
Proteins		
Protein	Kwashiorkor	Wasted muscles, thin limbs, retarded growth of body and brain, oedema, pot belly and diarrhoea.
Protein and Carbohydrate	Marasmus	Impaired growth and replacement of tissue proteins, thin limbs and prominent ribs (emaciated body), dry, wrinkled and thin skin, diarrhoea.
Minerals		
Iodine	Goitre	Swelling of the thyroid gland, reduced mental function, increased risk of stillbirths, abortions and infant deaths.
Iron	Anaemia, failure to mature RBC	Low haemoglobin condition, weakness, tiredness, reduced learning ability, increased risk of infection and even death during childbirth.
Vitamins		
Ascorbic Acid (C)	Scurvy (failure to form connective tissue)	Bleeding gums, loose teeth, anaemia, painful and swollen joints, delayed healing of wounds, and emaciation.
Biotin	Dermatitis	Scaly skin, muscle pains and weakness.
Calciferol (D)	Rickets in children Osteomalacia in adults	Weak and soft bones, distorted skeleton, poor muscular development.
Cyanocobal-amine (B_{12})	Pernicious anaemia	Large, immature and nucleated RBC devoid of haemoglobin.
Folic Acid	Macrocytic anaemia, malformed RBC	Impairment of antibody synthesis, stunted growth.
Menadione (K)	Severe bleeding	Slow or delayed blood clotting and haemorrhage (blood loss).
Niacin (nicotinic acid, nicotin-amide)	Pellagra and canine disease (black tongue)	Scaly, pigmented skin, irritation of the GI tract (diarrhoea).
Pyridoxine (B_6)	Dermatitis	Convulsions, impairment of antibody synthesis.
Retinol (A)	Night blindness	Dry, brittle or keratinised epithelia of skin, respiratory and urinogenital tracts, especially among children.

Riboflavin (B_2)	No specific disease Ariboflavinosis	Digestive disorder, burning sensation of the skin and eyes, lesions at the corners of the mouth, headaches, mental depression.
Tocopherol (E)	Haemolytic Anaemia	RBC devoid of haemoglobin.
Thiamine (B_1)	Beriberi	Loss of appetite, fatigue, muscle atrophy, paralysis, mental confusion, cardiac oedema.

body mass. Such a situation is attributed as **overnutrition**. Excess intake of saturated fats, like butter, ghee, vegetable oils, red meat, eggs, etc., often leads to **hypercholesterolemia**, a condition in which blood cholesterol content becomes abnormally high, ultimately leading to cardiac disorder. Deposition of cholesterol on the walls of blood vessels stiffens the blood vessels and increases blood pressure. Besides, excessive intake of calories (sugar, honey, ghee, etc.) may produce **overweight** and **obesity** (excessive accumulation of fat in tissues), which is the most common form of overnutrition. Very high intakes of minerals and fat-soluble vitamins (obtained from food sources alone) can be toxic. This is because they are stored in the body. With the exception of folic acid (women of child-bearing age), people who have well-balanced diets that supply enough energy do not usually need to take dietary supplements.

SUMMARY

Animals are heterotrophs that derive energy and building blocks from food, and basically depend on the autotrophs. The organic constituents of nutrients are carbohydrates, lipids, proteins and vitamins, and the inorganic constituents are minerals and water. These are contained in different types of food.

Heterotrophic nutrition may be holozoic, saprozoic, parasitic and symbiotic. Holozoic nutrition involves ingestion, digestion, absorption and egestion. Animals are variously adapted for ingestion (feeding) of food. Breaking down of the covalent bonds in the organic food molecules by hydrolysis (digestion) may be intracellular or extracellular. After digestion, the food is absorbed and converted into body substances. The undigested food is egested.

Most non-chordates and chordates (e.g. cockroach and human) have developed a complete digestive tract with two openings, mouth and anus. Cockroach and humans, have alimentary canal and associated digestive glands. In humans the alimentary canal consists of mouth, oral cavity, pharynx, oesophagus, stomach, small intestine, large intestine, rectum and anus. The accessory digestive glands include the salivary glands, the liver and the gall bladder and the pancreas. Tongue manipulates food during chewing and mixing with saliva. Swallowing is a reflex action that, along with peristaltic wave, pushes the food down the different sections of the gut.

Humans perform extracellular digestion with the aid of a group of enzymes, called hydrolases, released from the cells of the digestive system. Enzymatic hydrolysis begins in the mouth due to the action of amylase of saliva. Protein digestion begins in the stomach with pepsin and HCl present in the gastric juice. Four major layers of different cell types form the wall of the alimentary canal. The innermost layer (mucosa) is an epithelium that contains billions of mucous glands, which secrete mucus and protect the tissues of the gut. Partially digested broth of food, then, enters the duodenum as a chyme. Pancreatic acinar cells produce pancreatic juice that contains water and bicarbonate ions. It is released in the duodenum and mixes with the bicarbonate ions present there to form the intestinal juice. Digestion of most of the nutrients takes place in the duodenum under the action of various pancreatic enzymes. Liver and gall bladder produce bile and empty it into the duodenum. These secretions assist in the digestion of fats by breaking them into micelles. The process of digestion is coordinated and controlled by neural and gastrointestinal hormonal mechanisms.

After digestion, the simple foods (monosaccharides and amino acids) are absorbed through the microvilli of the intestinal mucosa by simple diffusion and Na-cotransport systems, and transported from the gut to different tissues and cells through the capillaries and the blood vessels. Fats are mostly absorbed as monoglycerides and fatty acids, which are resynthesised into triglycerides that, in turn, combine with cholesterol, and being coated with proteins form chylomicrons, which pass into the lymphatic system for circulation. Water and ions are absorbed in the large intestine. The undigested food is given out as faeces.

Minerals are ingested as salts dissolved in water, or as part of organic compounds. Vitamins are essential for normal metabolism, growth and sound health. Humans can synthesise vitamin A and D only. Minerals and vitamins, mostly do not require digestion. Deficiencies of nutrients, both organic and inorganic, in the food may result in specific diseases and disorders. Insufficient or excess calorie intake also causes a great deal of harm to the human body.

EXERCISES

1. Distinguish between autotrophic and heterotrophic nutrition.
2. Distinguish between holozoic and saprozoic nutrition.
3. Define nutrients. How do they help in the well-being of an organism?
4. Differentiate between proximate and protective principles of food.
5. Calcium is a ___________, but elements like iron are required in very __________ amount, and hence, they are called __________.
6. Match column I with column II :

Column I	Column II
(i) Lion	(a) Omnivore
(ii) Bats	(b) Sanguinivore

(iii) Cow	(c) Frugivore
(iv) Cockroach	(d) Carnivore
	(e) Herbivore

7. How does gastrovascular cavity in cnidarians help in digestion?
8. Crop, Midgut Hepatic caeca, Gizzard, Buccal cavity, Hindgut –arrange these parts of the alimentary canal of a cockroach in proper sequence in relation to digestion.
9. Write down the human dental formula. What is meant by diphyodont?
10. What is the function of oesophageal sphincter?
11. What are microvilli? State their functions.
12. Name the cell that secretes mucus. What are the functions of mucus?
12. What are crypts of Leiberkûhn?
14. Name three accessory digestive organs in humans.
15. What is peristalsis? How does it help in digestion?
16. Ptyalin is a starch digesting ________, secreted by ______ gland.
17. State the sources of vitamin A and vitamin C.
18. State the anatomical location of pancreas.
19. What are essential amino acids?
20. Mention calorific values of carbohydrate, protein and fat.
21. Distinguish between calorific and physiologic values.
22. What are the deficiency symptoms of vitamin A and D?
23. What do you understand by the term malnutrition?
24. State the physiologic functions of three fat-soluble vitamins.
25. State the physiologic functions of three water-soluble vitamins.
26. Distinguish between kwashiorkor and marasmus.

Chapter 6

Respiration in Animals

In the previous chapter, you have learnt that animals take in high-energy organic molecules in the form of food; they catabolise these food stuffs in presence of oxygen and obtain energy for various activities. As catabolism occurs in presence of oxygen, this process is known as **oxidation**. During this process, adenosine triphosphate (ATP) is synthesised, and energy is trapped by forming bonds between adenosine diphosphate (ADP) and inorganic phosphate (Pi). Where required, ATP breaks into ADP and Pi and releases bond energy for utilisation in the animal's body. This process is known as **aerobic respiration**. As it occurs in cells at the tissue level, it is also called **internal** or **cell respiration**. But from where does this oxygen come? It comes from the external environment in which the animal lives. However, oxidation may also occur in the absence of oxygen. This is referred to as **anaerobic respiration**. However, carbon dioxide, a toxic substance, is produced in both types of respiration. Animals must expel this toxic product. Thus, the exchange of internal carbon dioxide with external oxygen is a fundamental requirement of all animals.

In this chapter, you will be introduced to the mechanism of gaseous exchange in different animals, including humans. Also, you will come to know about the structures associated with this function, and the mode of transport of carbon dioxide and oxygen in different animals and humans. At the end, we shall discuss some human respiratory disorders.

6.1 Gaseous Exchange in Animals

As the goals of respiration are to provide oxygen to the tissues and to remove carbon dioxide from them, respiration may be defined as the uptake of oxygen and giving out of carbon dioxide. Free-living acellular protists and multicellular animals exchange gases with their surrounding environment. Protozoans, poriferans and cnidarians obtain oxygen dissolved in water by diffusion through their body surfaces. Carbon dioxide follows the opposite path and is released through body surfaces. Most of the higher aquatic invertebrates have developed gills for aquatic mode of respiration. Gills are also the characteristics of fish (Fig. 6.1). Terrestrial animals (e.g. amphibians, reptiles, birds and mammals), on the other hand, have developed lungs for aerial mode of respiration (Fig. 6.2).

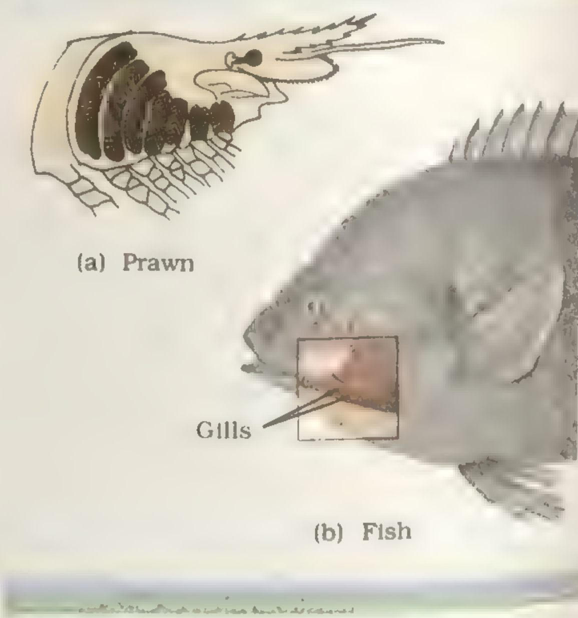


Fig. 6.1 *Gills of prawn and fish for aquatic mode of respiration*

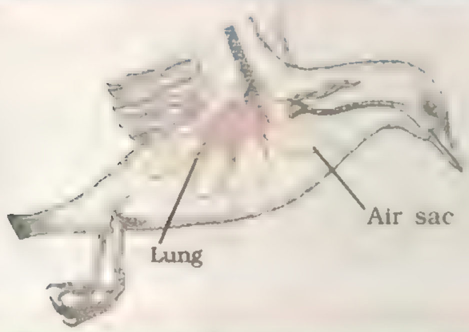


Fig. 6.2 *Lungs of birds for aerial mode of respiration*

Earthworms do not have a respiratory organ. They exchange O_2 and CO_2 between their looped epidermal blood capillaries and moist skin. Their epidermis has a rich network of blood capillaries, and their body surface has a moist film containing secretions of epidermal mucous glands, excretory wastes and coelomic fluids. The epidermal capillaries that, in turn, release the carbon dioxide, take up the oxygen dissolved in the film of surface moisture.

There is no red blood corpuscle to carry the oxygen molecules. The respiratory pigment, **haemoglobin**, remains dissolved in the blood plasma; the oxygen tension, or partial pressure of oxygen in blood, is low relative to the moist skin. Hence, the dissolved oxygen binds with haemoglobin of the plasma. Contractile pumping activity by the blood vessels facilitates the transport of blood and the dissolved gases round the body and maintain steep diffusion gradients.

Cockroaches have an organised respiratory system consisting of tubules forming the **tracheal system.** The tubules are highly branched and cover almost the entire body cavity or **haemocoel**. Three pairs of longitudinal tracheal trunks are present all along the length of the body, which are further connected with each other with the help of transverse branches [Fig. 6.3(a)]. From each tracheal trunk, three branches come out. The dorsal branch is supplied to the dorsal

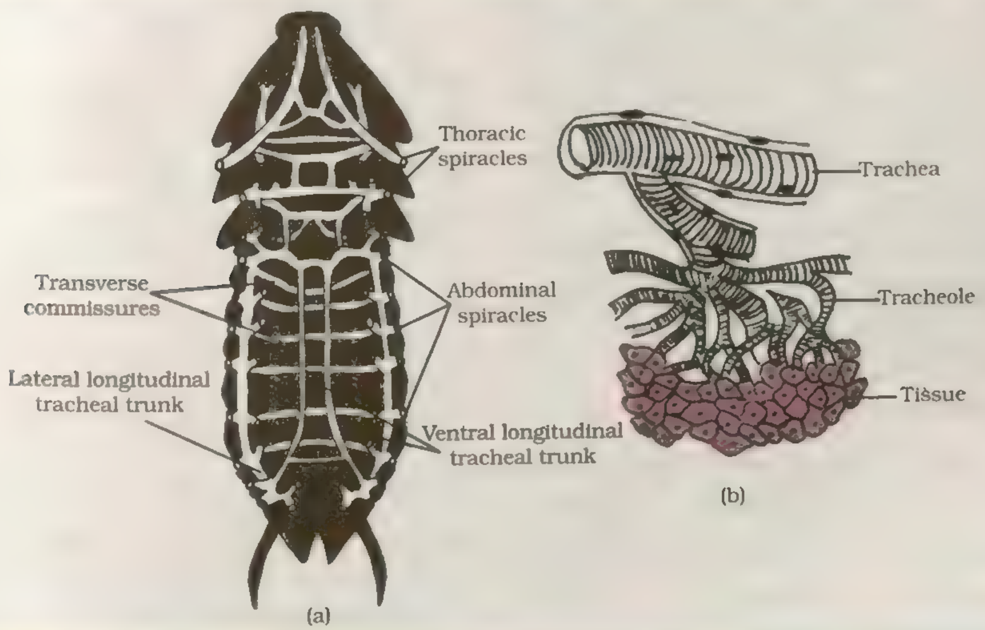


Fig. 6.3 *(a) Tracheal system of cockroach (b) System of trachea and tracheole*

muscles, whereas the ventral one to nerve cord and ventral muscles, and the middle one to the alimentary canal. These branches divide and redivide into finer branches [Fig. 6.3(b)]. These longitudinal tracheal trunks communicate with the exterior through 10 pairs of openings, called **spiracles**. Of these, two pairs are present in the thorax and one pair in each of the first eight abdominal segments. Each spiracle is surrounded by an annular **sclerite (peritreme)**, which extends inward and opens into an air-filled cavity, called the **atrium** or **tracheal chamber**; the atrium continues as branched tubules or **trachea**. In each segment, the tracheae branch into numerous small tubules, called **tracheoles**, which ramify in the tissues and end blindly.

The abdominal segments are provided with tergo-sternal muscles. The contraction and the relaxation of these muscles cause a rhythmic contraction and expansion of the abdominal cavity. Expansion of the abdominal cavity allows the space inside the tracheal trunk to expand. As a result, air enters through the spiracles and is distributed in the body cavity through the tracheal system. Gaseous exchange takes place between tissues and the air present in the tracheoles. When the abdominal cavity contracts, the tracheal system also contracts, the pressure of the air inside the tracheal system increases, causing the release of air to the outside.

At rest, the tracheoles are filled with watery fluid, and diffusion of oxygen and carbon dioxide takes place to fulfil the requirement of the insect. However, during exercise, the fluid in the tracheoles is drawn osmotically into the tissues. Consequently, more air rushes into the tracheoles.

6.2 Respiration in Humans

Humans have a well-developed respiratory system. Human respiration involves activities like inspiration (breathing in), expiration (breathing out), exchange of gases in the lungs and its transport to the tissues.

Human Respiratory System

The human respiratory system consists of external nares or nostrils, nasal cavity,

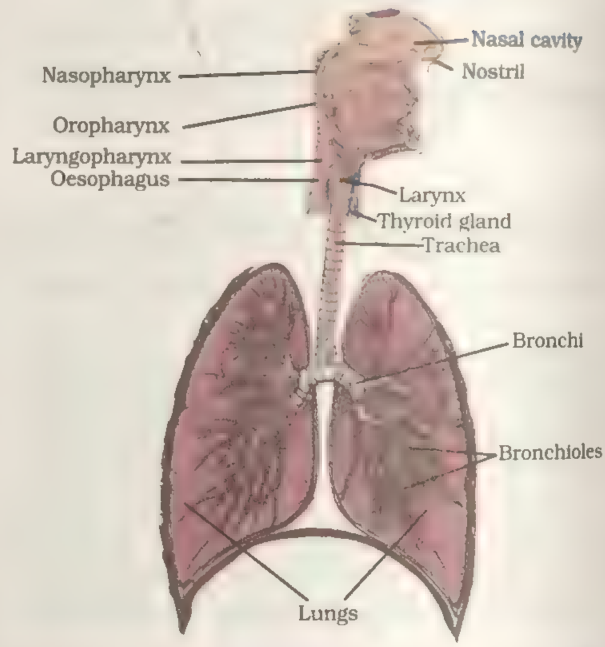


Fig. 6.4 *Human respiratory system*

nasopharynx, larynx, trachea, bronchi, bronchiole and lungs (Fig. 6.4). The external opening of the respiratory system is a pair of external **nares** or **nostrils**. Air enters into the nasal cavity through the nostrils. The nasal cavity opens into the posterior part of pharynx. The uppermost part of the pharyngeal cavity is termed **nasopharynx**. Pharyngeal areas behind the buccal cavity and larynx are called **oropharynx** and **laryngopharynx**, respectively. Larynx is a small box and it forms the connection between pharynx and the windpipe or trachea (Fig. 6.5). A large leaf-like cartilaginous epiglottis guards the opening of the larynx, called **glottis**. Treachea is a tubular structure of about 12 cm in length and 2.5 cm in diameter; it starts posterior to larynx and extends up to the middle of the thoracic cavity where it divides into right and left primary bronchi that enter into the lungs. The tracheal

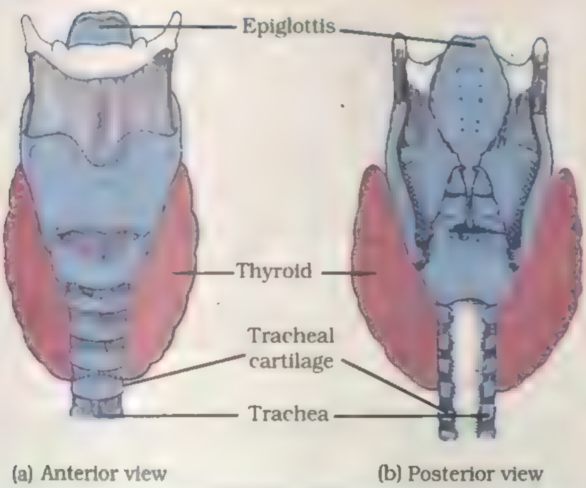


Fig. 6.5 Human larynx

tubule is supported by incomplete (C-shaped) ring of cartilage at regular intervals to prevent collapsing of the tubule. In each lung, the

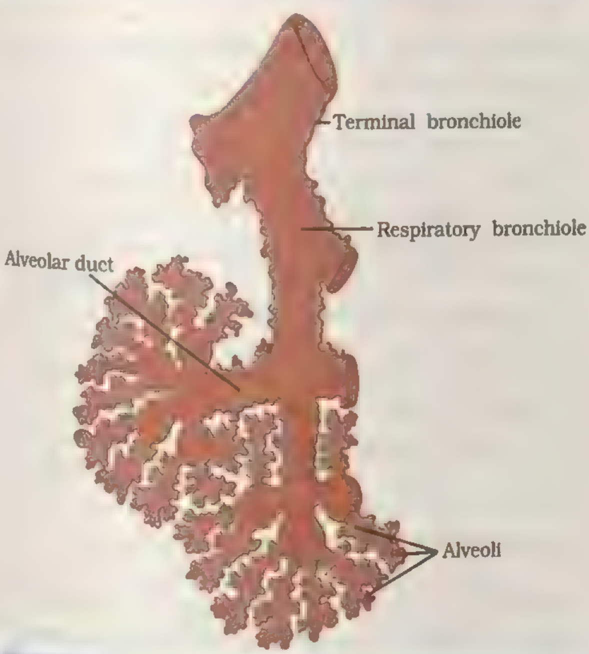


Fig. 6.6 Terminal bronchiole and alveoli

bronchus divides and redivides to from secondary bronchi, tertiary bronchi, bronchiole and, ultimately the terminal bronchioles, that further subdivide into many alveolar ducts that lead into the alveoli or air sac (Fig. 6.6). There are about 300 million alveoli in the two lungs. Lungs are paired structure present in the thoracic or pleural cavity. A double-layered pleural membrane encloses the lung for its protection. The outer layer of pleura remains attached to the wall of the thoracic cavity. The space between the two pleural membranes contains a fluid secreted by its wall, which reduces friction and makes the movement of lungs easy.

Mechanism of Respiration

The main purpose of respiration is to provide oxygen to the tissues and to remove carbon dioxide from them. This entire process is accomplished in three steps : breathing or pulmonary ventilation, exchange of oxygen and carbon dioxide, and transport of gases in blood.

Breathing and pulmonary ventilation : It means the inflow (inspiration) and outflow (expiration) of air between atmosphere and the alveoli of the lung. Breathing is effected by the expansion and contraction of lungs. There are two processes by which the lungs are expanded or contracted :

(i) The downward and upward movement of the diaphragm, which lengthens and shortens the chest cavity.

(ii) The elevation and depression of the ribs, which increase or decrease the diameter of the chest cavity.

During expansion, the volume of lungs increases. As a result, the pressure of air inside the lung decreases. In order to bring the pressure at normal level, atmospheric air is inhaled. When the lungs contract, their volumes decrease, resulting in the increase of air pressure in lungs. Hence, the air is exhaled from the lungs. These two processes are called inspiration and expiration, respectively. During normal or quiet breathing, the downward and upward movement of the diaphragm takes place. When the diaphragm contracts, the lower surface of the lung is pulled downward.

Consequently, the volume of the lungs increases. This causes inhalation of air or inspiration. During exhalation of air or expiration, the diaphragm relaxes and the lungs are compressed (Fig. 6.7).

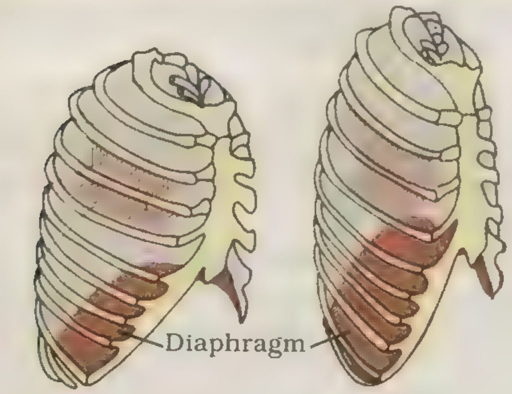


Fig. 6.7 *Diaphragm movement during breathing*

During exercise, the rate of breathing increases due to the increased demand for oxygen. The elastic force, resulting from contraction and relaxation of diaphragm, is not sufficient for this purpose. The demand of extra oxygen is fulfilled by the expansion of rib cage. Either of the two movements, or both, create a partial pressure or reduction of air pressure inside the thoracic cavity, including the lungs. This results into the rushing of air in the lungs to fill up the space and equalise the air pressure.

When we breathe out, the capacity of thoracic cavity decreases due to the inward, as well as downward movement of the rib cage along with upward movement of the diaphragm. A high pressure is generated in the lungs and air moves out (expiration). The upward movement of rib cage is caused mainly by the external intercostal muscles present between the ribs, along with the assistance of few other adjacent muscles. Similarly, the downward movement of rib cage is facilitated by the internal intercostals, external oblique and internal oblique muscles (Fig. 6.8).

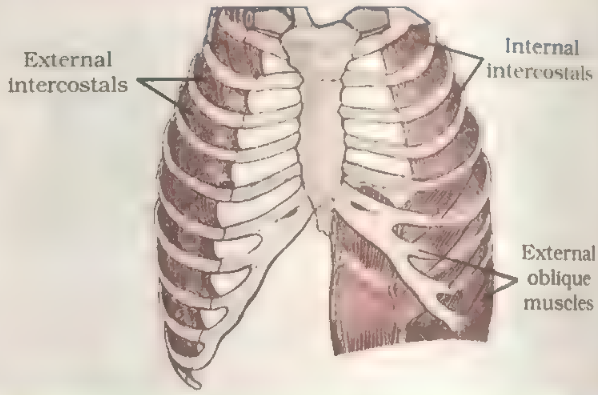


Fig. 6.8 *Muscles involved in respiration*

The volume of air inspired and expired with every normal breath during effortless respiration is called the **tidal volume** (TV is about 500 ml of air). Sometimes, extra amount of air can be forcefully inspired. The extra volume of air that can be inspired beyond the normal tidal volume is called **inspiratory reserve volume** (IRV, is about 2500-3000 ml of air). Similarly, an extra amount of air can be expired forcefully even beyond the normal tidal expiration. The measure of this capacity of lung is called **expiratory reserve volume** (ERV, is about 1000 ml of air). Even after a forceful expiration to maximum capacity, some amount of air remains in the lung. It is called **residual volume** (RV, is about 1200 ml of air).

When any two or more of the above-mentioned pulmonary volumes are considered together, such combinations are called **pulmonary capacities**. The total amount of air a person can take in distending the lungs to the maximum, beginning at normal expiratory level, is called **inspiratory capacity** (IC, is about 3000-3500 ml of air). It is equal to the sum of tidal volume and inspiratory reserve volume (IC = TV + IRV). When a person breathes normally, then, the amount which remains in the lung after normal expiration, is called **functional residual capacity** (FRC, is

about 2500 ml of air). It can be measured as the total of expiratory reserve volume and the residual volume (FRC = ERV + RV). **Vital capacity** (VC) is an important measure of pulmonary capacity. It is the maximum amount of air a person can expel from the lungs after first filling the lungs to their maximum extent (VC varies from 3400 ml to 4800 ml, depending on age, sex and height of the individual). Vital capacity is the sum total of inspiratory reserve volume, tidal volume and expiratory reserve volume (VC = IRV + TV + ERV).

Exchange of gas : The inspired air ultimately reaches the alveoli of the lung, which, in turn, receives the blood supply of the pulmonary circulation. At this place, the oxygen of the inspired air is taken in by the blood, and carbon dioxide is released into the alveoli for expiration. These respiratory gases move freely by the process of diffusion. The kinetic motion of the molecules provides the energy required for this diffusion of gaseous molecule itself. Diffusion of any molecule takes place from high to low concentration.

The process of diffusion is directly proportional to the pressure caused by the gas alone. The pressure exerted by an individual gas is called **partial pressure**. It is represented as Po_2, Pco_2, PN_2 for oxygen, carbon dioxide and nitrogen, respectively.

Inside the alveoli, the inspired air remains in a very close contact with blood. It is because the alveolar wall is very thin and contains a rich network of interconnected capillaries. Due to this, the alveolar wall seems to be a sheet of flowing blood, and is called the **respiratory membrane**. It consists mainly of the alveolar epithelium, epithelial basement membrane, a thin interstitial space, capillary basement membrane and capillary endothelial membrane. All these layers cumulatively form a membrane of 0.2 mm thickness (Fig. 6.9). The respiratory membrane has a limit of gaseous exchange between alveoli and pulmonary blood. It is called **diffusing capacity**, and is defined as the volume of gas, that diffuses through the membrane per minute for a pressure difference of 1 mm Hg. It is further dependent on the solubility of the diffusing

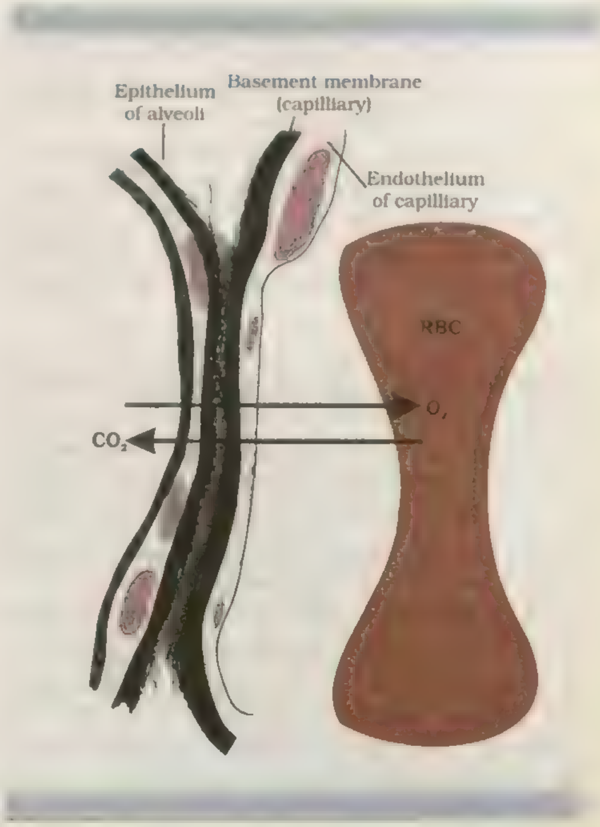


Fig. 6.9 *Respiratory membrane for gaseous exchange*

gases. In other words, at a particular pressure difference, the diffusion of carbon dioxide is 20 times faster than oxygen, and that of oxygen is two times faster than nitrogen. Due to the existing pressure difference of oxygen, and carbon dioxide between the alveoli and the blood capillaries, oxygen diffuses from alveolar air to the capillary blood, whereas carbon dioxide diffuses from capillary blood to the alveolar air.

Transport of gases in blood : Blood is the medium for the transport of oxygen from the respiratory organ to the different tissues, and carbon dioxide from tissues to the respiratory organ. The pulmonary vein supplies oxygenated blood to the left atrium, from where it is pumped into left ventricle, and ultimately, to the different tissues of the body. As much as 97 per cent of the oxygen is transported from the lungs to the tissues in combination with

haemoglobin ($Hb + O_2 \rightarrow HbO_2$, oxyhaemoglobin), and only 3 per cent is transported in dissolved condition by the plasma. Under the high partial pressure, oxygen easily binds with haemoglobin in the pulmonary capillaries. When this oxygenated blood reaches the different tissues, the partial pressure of oxygen declines and the bonds holding oxygen to haemoglobin become unstable. As a result, oxygen is released from the capillaries.

Under strenuous conditions, or during exercise, the muscle cells consume oxygen at a comparatively faster rate. The partial pressure of oxygen in the tissue falls, as a result of which, the blood at the tissue level has merely 4.4 ml of oxygen/100 ml of blood. Thus, approximately 15 ml of oxygen is transported by haemoglobin during exercise.

In a normal and healthy person, the measurement of haemoglobin is approximately 15 g per 100 ml. The capacity of 1 g of haemoglobin to combine with oxygen is 1.34 ml. Thus, on an average, 100 ml of blood carries about 20 ml (19.4 ml exactly) of oxygen. When blood reaches the tissues, its oxygen concentration is reduced gradually to 14.4 ml, which is then collected by the veinules and veins. Thus, under normal conditions, approximately 5 ml of oxygen is transported by 100 ml of blood. This can be verified by deducting the quantity of oxygen of venous blood from that of arterial blood.

The amount of oxygen that can bind with haemoglobin, is determined by oxygen tension. This is expressed as a partial pressure (Po_2), that is the fraction of atmospheric oxygen. Figure 6.10 shows the saturation level of haemoglobin in relation to the Po_2 of blood. Haemoglobin cannot take up oxygen beyond a saturation level of 95 per cent. A 100 per cent saturation of haemoglobin is rare. At lower Po_2, oxygen is released from haemoglobin. It is 50 per cent saturated at 30 mm of Hg. Haemoglobin would be completely free from oxygen at zero Po_2. This relationship is expressed by plotting the oxygen saturation of blood against the Po_2 of oxygen. An S-shaped curve, called **oxygen dissociation curve**, is obtained. It is dependent on Po_2, Pco_2 temperature and pH.

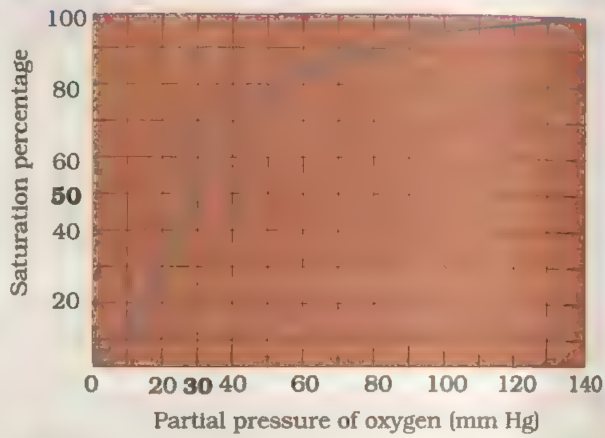


Fig. 6.10 *Oxygen dissociation curve*

The blood transports carbon dioxide comparatively easily because of its higher solubility. There are three ways of transport of carbon dioxide.

(a) In dissolved state : Approximately 5-7 per cent of carbon dioxide is transported, being dissolved in the plasma of blood. The partial pressures (Pco_2) of the venous blood and arterial blood is 45 mm of Hg (i.e. 2.7 ml of CO_2/100 ml) and 40 mm of Hg (2.4 ml CO_2/100 ml), respectively. Hence, 0.3 ml of carbon dioxide is transported per 100 ml of blood.

(b) In the form of bicarbonate : Carbon dioxide produced by the tissues, diffuses passively into the blood stream and passes into the red blood corpuscles, where it reacts with water to form carbonic acid (H_2CO_3). This reaction is catalysed by the enzyme, carbonic anhydrase, found in the erythrocytes, and takes less than one second to complete the process. Immediately after its formation, carbonic acid dissociates into Hydrogen (H^+) and bicarbonate (HCO_3^-) ions.

The oxyhaemoglobin (HbO_2) of the erythrocytes is acidic and remains in association with K^+ ions as $KHbO_2$. The hydrogen ions (H^+) released from carbonic acid combine with haemoglobin after its dissociation from the potassium ions.

The majority of bicarbonate ions (HCO_3^-) formed within the erythrocytes diffuse out into the plasma along a concentration gradient. These combine with haemoglobin to form the haemoglobinic acid (H.Hb).

$$
\begin{aligned}
& \qquad\quad \text{Carbonic anhydrase} \\
& \qquad\qquad\qquad \downarrow \\
CO_2 + H_2O &\rightleftarrows H_2CO_3 \\
H_2CO_3 &\rightleftarrows H^+ + HCO_3^- \\
KHbO_2 &\rightleftarrows KHb + O_2 \\
H^+ + HCO_3 + KHb &\rightleftarrows H.Hb + KHCO_3
\end{aligned}
$$

In response, chloride ions (Cl^-) diffuse from plasma into the erythrocytes to maintain the ionic balance. Thus, electrochemical neutrality is maintained. This is called **chloride shift** (Fig. 6.11). The chloride ions (Cl^-) inside RBC combine with potassium ion (K^+) to form potassium chloride (KCl), whereas hydrogen carbonate ions (HCO_3^-) in the plasma combine with Na^+ to form sodium hydrogen carbonate ($NaHCO_3$). Nearly 70 per cent of carbon dioxide is transported from tissues to the lungs in this form (Fig. 6.11).

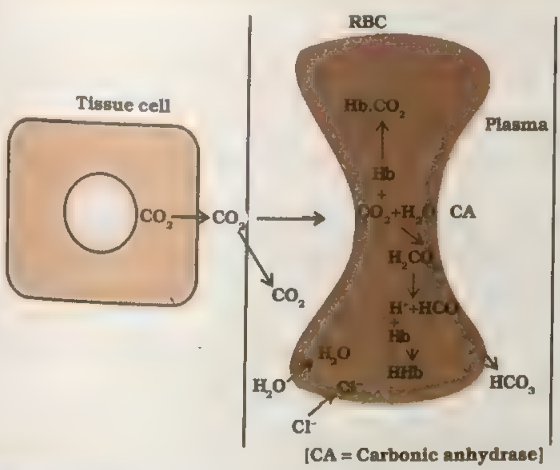


Fig. 6.11 *Carbon dioxide transport and chloride shift*

(c) In combination with amine group of protein : Besides the above two methods, carbon dioxide reacts directly with the amine radicals (NH_2) of haemoglobin molecule and forms a carbaminohaemoglobin ($HbCO_2$) molecule. This combination of carbon dioxide with haemoglobin is a reversible reaction. Nearly 23 per cent of carbon dioxide is transported through this mode.

Release of carbon dioxide in the alveoli of lung : When the deoxygenated blood reaches the alveoli of the lung, it contains carbon dioxide as dissolved in plasma, as carbaminohaemoglobin, and as bicarbonate ions. In the pulmonary capillaries, the carbon dioxide dissolved in plasma diffuses into alveoli. Carbaminohaemoglobin also splits into carbon dioxide and haemoglobin. For the release of carbon dioxide from the bicarbonate, a small series of reverse reactions takes place. When the haemoglobin in the pulmonary blood takes up oxygen, the H^+ is released from it. Then, the Cl^- and HCO_3^- ions are released from KCl in blood, and $KHCO_3$ in the RBC, respectively. Then HCO_3^- reacts with H^+ to form H_2CO_3. This H_2CO_3, ultimately, then splits into carbon dioxide and water in the presence of carbonic anhydrase enzyme and carbon dioxide is released into lungs.

6.3 Regulation of Respiration

The respiratory rhythm is controlled by the nervous system. The rate of respiration can be enhanced as per demand of the body during strenuous physical exercises. A number of groups of neurons located bilaterally in the medulla oblongata control the respiration. These are called **respiratory centres**. Three groups of respiratory centres have been identified, namely : dorsal respiratory group, ventral respiratory group and pneumotaxic centre (Fig. 6.12).

The dorsal respiratory group is present in the dorsal portion of medulla oblongata. The signals from these neurons generate the basic respiratory rhythm. The nervous signal released from this group is transmitted to the diaphragm, which is the primary inspiratory muscle. The ventral respiratory group of

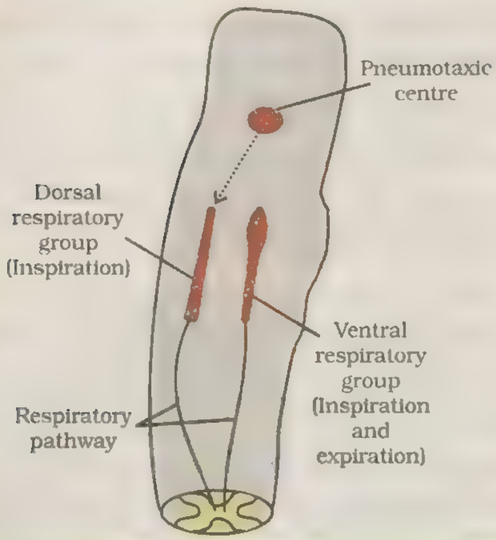


Fig. 6.12 *Respiratory centres in brain*

neurons is located anterolateral to the dorsal respiratory group. During normal respiration, this remains inactive and even does not play any role in the basic respiratory rhythm. But, under the enhanced respiratory drive, the respiratory signal of this group contributes to fulfil the demand by regulating both inspiration and expiration. Few of the neurons of this group control inspiration, while few other control expiration, thus regulating both. The pneumotaxic centre is located dorsally in the upper pons. It transmits signals to the inspiratory area. Primarily, it controls the switch off point of inspiration. When this signal is strong, the inspiration lasts only for 0.5 seconds, and lungs are filled partially. During weak pneumotaxic signal, inspiration lasts for 5 seconds, or more, resulting into complete filling of lungs. The strong signal causes increased rate of breathing because inspiration, as well as expiration, is shortened.

The concentration of CO_2 and H^+ cause increased strength of inspiratory, as well as expiratory signal. However, oxygen has no such direct effect.

6.4 Respiratory Disorders

(a) Bronchitis : It is the inflammation of the bronchi, which is characterised by hypertrophy and hyperplasia of sero-mucous gland and goblet cells lining the bronchi. The symptom is regular coughing, with thick greenish yellow sputum that indicates the underlying infection, resulting in excessive secretion of mucous. It may also be caused by cigarette smoking and exposure to air pollutants like carbon monoxide.

Prevention and cure : Avoiding exposure to the cause, i.e. smoke, chemicals and pollutants, can prevent Bronchitis. The underlying infection of the disease is treated with suitable antibiotics. Bronchodilator drugs (for widening the constriction of bronchial passage by relaxing the smooth muscles) provide symptomatic relief.

(b) Bronchial Asthma : This is characterised by the spasm of the smooth muscles present in the walls of the bronchiole. It is generally caused due to hypersensitivity of the bronchiole to the foreign substances present in the air passing through it. The symptoms of the disease may be coughing, or difficulty in breathing mainly during expiration. The mucous membranes on the wall of the air passage start secreting excess amount of mucous, which may clog the bronchi, as well as bronchioles.

Prevention and cure : It is an allergic disease hence, avoiding exposure to the foreign substance or allergens is the best preventive measure. In case the patient is sensitive to a very few number of allergens, then hyposensitisation (by exposing small doses of the specific allergen) is the other preventive measure. Treatment of the disease includes antibiotic therapy for removing the infection, and use of bronchodilator drugs, as well as inhalers for symptomatic relief.

*(c) **Emphysema** :* It is an inflation or abnormal distension of the bronchiole or alveolar sac, which results in the loss of elasticity of these parts. As a result, the alveolar sac remains filled with air even after expiration, and ultimately, the lung size increases.

The reason for such a condition can be assigned to cigarette smoking and chronic bronchitis.

Prevention and cure : Emphysema is a chronic obstructive disease of lung, causing irreversible distension and loss of elasticity of alveoli. Hence, it can't be cured permanently. However, treatment may retard the progression of the disease. Its treatment is also symptomatic. Bronchodilators, antibiotics and oxygen therapy are used. This disease is preventable if chronic exposure to smoke (cigarette and others) and pollutant is avoided.

(d) Pneumonia : It is an acute infection or inflammation of the alveoli of the lung. This disease is caused mainly due to infection of the bacteria (*Streptococcus pneumoniae*). Sometimes, other bacteria or fungi, protozoan, viruses and mycoplasma may also be responsible. Infants, elderly persons and immuno compromised individuals are susceptible to it. In this disease, most of the air space of the alveolar sac is occupied by the fluid with dead WBC. Uptake of oxygen is adversely affected in the inflamed alveoli, as a result of which, the oxygen level of the blood falls.

Prevention and cure : Since infection is the main cause of pneumonia, use of antibiotics to remove the infection cures it. Patient may require symptomatic treatment like bronchodilator drugs. In case of immunocompromised individuals, the disease can be prevented by proper and timely vaccination.

(e) Occupational Lung Disease : It is caused because of the exposure of potentially harmful substances, such as gas, fumes or dusts, present in the environment where a person works. Silicosis and asbestosis are the common examples, which occur due to chronic exposure of silica and asbestos dust in the mining industry. It is characterised by fibrosis (proliferation of fibrous connective tissue) of upper part of lung, causing inflammation.

Prevention and cure : Almost all the occupational lung diseases, express symptoms after chronic exposure, i.e. 10-15 years or even more. Not only this, diseases like silicosis and asbestosis are incurable. Hence, the person likely to be exposed to such irritants, should adopt all possible preventive measures, These measures include :

(i) Minimising the exposure of harmful dust at the work place.
(ii) Workers should be well informed about the harm of the exposure to such dusts.
(iii) Use of protective gears and clothing by the workers at the work place.
(iv) Regular health check up.
(v) Holiday from duty at short intervals for the workers in such areas.

The patient may be provided with symptomatic treatment, like bronchodilators and antibiotics, to remove underlying secondary infection.

SUMMARY

Animals need to inhale oxygen for the breakdown of food to produce energy. This process results into the release of carbon dioxide. Carbon dioxide is harmful for animals, hence, it is required to be exhaled. This entire process is called respiration. Respiration involving oxygen is called aerobic respiration, and that without it, is designated as anaerobic respiration.

Almost all the animals take up oxygen and release carbon dioxide. In aquatic animals, gills perform this activity, while in the land animals, lungs and tracheal system do the same. Earthworm respires through moist and vascularised skin. Cockroach has an elaborate tracheal system throughout the body for aerial respiration.

Humans have an organised respiratory system, with lung as the respiratory organ. Air enters into the lung through nasal cavity, pharynx, trachea and bronchi. Lung contains enormous air sacs or alveoli, which are

highly vascular for the purpose of gaseous exchange. After gaseous exchange, oxygen is transported to the tissues with haemoglobin present in the blood. Carbon dioxide formed in the tissues due to oxidation of food is transported to the lung by the blood in three forms, i.e. dissolved in plasma; as bicarbonate ions in the plasma from where they pass into the erythrocytes; and in combination with haemoglobin.

The process of respiration is under nervous control of the respiratory centres present in the medulla oblongata.

The inflammation, hypersensitivity to foreign substances, infection and deposition of particles or dust in parts of respiratory organ, cause a number of disorders. Common lung ailments are bronchitis, bronchial asthma, emphysema, pneumonia and occupational lung disease.

EXERCISES

1. How does respiration fulfil the energy requirement of an organism?
2. Define the following terms :
   (a) Anaerobic respiration
   (b) Breathing
   (c) Vital capacity
   (d) Tidal volume
   (e) Respiratory centre.
3. Write the names of the respiratory organs present in human beings.
4. How does the skin of earthworm help in respiration?
5. Write the role of diaphragm and intercostal muscles in the breathing process.
6. What is partial pressure? How does it help in gaseous exchange during respiration?
7. How does haemoglobin help in the transport of oxygen from lung to tissues?
8. What is the role of carbonic anhydrase enzyme in the transport of gases during respiration?
9. What is chloride shift? Write its significance during respiration.
10. Write true or false :
    (a) Inspiratory reserve volume is the volume of air, which can be inspired in addition to the normal inspiration.
    (b) Vital capacity is a measure of maximum inspiration.
    (c) During gaseous exchange the gases diffuse from high partial pressure to low partial pressure.
    (d) Carbon dioxide cannot be transported with haemoglobin.
    (e) Earthworm respires through parapodia.
11. Fill in the blanks :
    (a) ________ ml of oxygen is transported per decilitre of blood.
    (b) Total lung capacity is ________ ml.
    (c) There are ________ pairs of spiracles in cockroach.
    (d) Lung is enclosed by ________ membrane.
    (e) ________ bacteria cause pneumonia.
12. Explain the main features of respiration in cockroach.

Chapter 7

Circulation in Animals

Circulation simply means the movement of protoplasm inside the cell. In Chapters 5 and 6, you have seen that acellular protists circulate their nutrients through cytoplasmic streaming. Majority of multicellular animals have developed a circulatory system for mass transport of nutrients and respiratory gases. Besides transport of metabolites and gases, animals need to remove the waste products formed in their tissues; they are to transport hormones to the target tissues and maintain homeostasis. All such functions are performed by the circulatory system. Vertebrates possess an elaborate circulatory system, that includes the blood vascular system (blood, heart and blood vessels) and lymphatic system (lymph and lymph vessels). In this chapter, you will be acquainted with the circulation of body fluid in some animals, including humans. Emphasis will be given on the composition of blood; structure and function of heart, and blood-related diseases in humans. Also, you will learn some technological applications, which are used for detecting and checking heart-related problems.

7.1 Open and Closed Systems

Blood vascular system is basically of two types : open and closed.

In **open type**, the blood is pumped by the heart into the blood vessels that open into blood spaces (sinuses). There is no capillary system (i.e. most arthropods, some molluscs except cephalopods and tunicates). These sinuses are actually the body cavities, and are called the **haemocoel**. The pressure of the blood is low; it moves slowly between the tissues, and finally, returns to the heart via the open-ended veins. In fact, distribution of blood to the tissues is very poorly controlled. The pigments, which carry oxygen, remain dissolved in blood plasma. Body tissues and visceral organs exchange respiratory gases, nutrients and waste products, directly with blood.

Many invertebrates and all the vertebrates, including humans, have a closed circulatory system. In closed type, the blood flows around the body through the specific blood vessels. In this system, the blood regularly circulates in the body under high pressure, and returns back to the heart without leaving the system of tubes. The heart pumps the blood into the aorta, which branches in the body into the arteries, and in the tissues into the arterioles, to form the capillary network. The venules of the capillary network carry the blood back to heart via veins and vena cava. This helps in supplying the nutrients and oxygen to the tissues, and removing waste materials and carbon dioxide from it. Table 7.1 reveals a comparison between open and closed circulatory systems.

7.2 Circulatory System of Cockroach

The circulatory system of cockroach is of open type. It consists of the heart or dorsal blood vessel, sinuses, and the haemolymph. The colourless haemolymph fills the entire

Table 7.1 : Comparison of Open and Closed Circulatory Systems

Open System	Closed System
These are usually low pressure systems.	These are usually high pressure systems.
Blood is conveyed directly to the organs without formation of capillaries.	Blood is conveyed directly to the organs through capillaries.
Distribution of blood to different organs is not well regulated.	Distribution of blood to different organs is well regulated.
Blood returns to the heart slowly.	Blood returns to the heart rapidly.
Found in most arthropods. molluscs except cephalopods and tunicates	Found in cephalopods (octopus, squids) echinoderms and vertebrates.

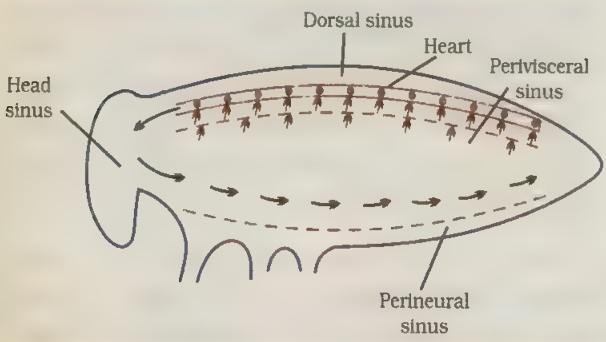


Fig. 7.1 *Three sinuses in Cockroach*

haemocoel. The haemocoel is divided into three chambers, or sinuses : dorsal, middle and ventral by diaphragm (Fig. 7.1). The dorsal chamber is called **pericardial sinus** because it contains the heart in it. The middle one possessing the visceral organs is the **perivisceral sinus**, whereas the ventral one containing the ventral nerve cord is the **perineural sinus**. The dorsal and ventral diaphragms bear a number of pores through which haemolymph flows from one chamber to the other. The **heart** of cockroach is an elongated tubular structure, closed behind and open in front, extended along the mid-dorsal line of thorax and abdomen. It has thirteen funnel-shaped and segmentally arranged chambers, i.e., three in the thoracic segment and ten in the abdominal segments (Fig. 7.2). Externally, these chambers can be distinguished due to the presence of constrictions. Valves, ensuring the unidirectional flow of blood, guard the narrow passage of each heart chamber. Blood flows forward, i.e., from posterior to anterior end, and is discharged into the tissue spaces of the head region. Laterally, each heart chamber bears a pair of apertures called **ostia**, guarded by valves, through which it communicates with pericardial sinus. At the

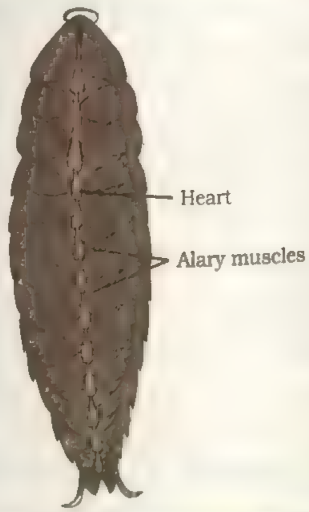


Fig. 7.2 *Elongated heart of Cockroach*

anterior end, the heart vessel opens into head sinus. In each segment, a pair of triangular **alary muscles** is present on the either side of the heart.

Haemolymph is a colourless fluid made up of plasma and haemocytes. Plasma contains amino acids and uric acid. There are different types of haemocytes, or amoebocytes, in plasma. The haemocytes are responsible for phagocytosis, coagulation and wound healing. Interestingly, neither the haemocytes, nor plasma, contains any respiratory pigment. The blood of cockroach is not responsible for the transportation of respiratory gases, but serves for : (i) the transportation of nutrients, (ii) maintains hydrostatic pressure, and (iii) acts as a reservoir of water. The haemolymph of cockroach circulates due to contraction and relaxation of the heart and the alary muscles. The contraction of alary muscles stretches the dorsal diaphragm, resulting in an increase in the volume of pericardial sinus. Due to this, the blood flows into the heart from perivisceral sinus. The relaxation of the muscles result in the entry of blood from pericardial sinus into heart through ostia. The peristaltic contraction wave of heart, from posterior to anterior end, pushes the haemolymph into the head sinus from where it returns to the perivisceral and perineural sinus.

7.3 Blood Vascular System of Humans

The human blood vascular system is an example of closed type with a muscular heart, blood (fluid plasma and blood corpuscles) and blood vessels (arteries and veins).

Human Blood

It is a complex fluid connective tissue, which consists of two components :

(i) Plasma
(ii) Blood corpuscles.

Plasma : It is the extracellular fluid of blood constituting about 55 per cent of the blood volume. It is a faint yellow coloured viscous fluid, which is alkaline in nature. Plasma contains 91-92 per cent of water, 7 per cent of proteins, 0.9 per cent inorganic constituents, 0.1 per cent of glucose, and the rest includes various other organic and inorganic substances. Proteins are the second largest constituents of plasma. Albumins, globulins and fibrinogen are the important types of proteins present in the plasma. Albumin provides the colloid osmotic pressure in plasma. These proteins act as enzymes, coagulating factors and antibodies. The dissolved mineral ions (Na^+, K^+, Ca^{2+}, Mg^{2+}, HPO_4^{2-}, PO_4^{3-}, Cl^-, HCO_3^- etc.) maintain the pH of blood by buffering action.

Blood corpuscles : Nearly 45 per cent volume of blood consists of corpuscles or blood cells. The blood corpuscles are of three types : erythrocytes or red blood corpuscles (RBC), leucocytes or white blood corpuscles (WBC), and thrombocytes or blood platelets (Fig. 7.3).

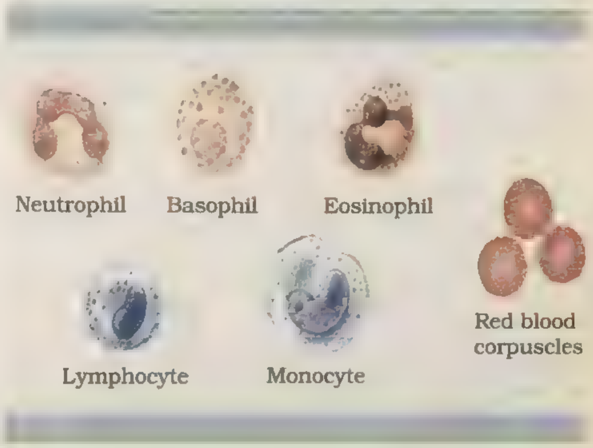


Fig. 7.3 *Different blood corpuscles*

Erythrocytes are the most prevalent corpuscles (approximately 4.5 to 5.5 million/mm^3) and have a biconcave disc-like shape with a diameter of 7-8 μm. The erythrocytes contain sufficient amount of **carbonic anhydrase** enzyme, which catalyses the reaction between carbon dioxide and water, and helps in transport of carbon dioxide from tissues to the lungs. You have already studied about this aspect in Chapter 6. Like other mammals, the human RBC also lacks nucleus.

The average life span of RBC is 120 days, after which it is destroyed.

The RBC, due to the presence of haemoglobin, carries out the most important function of blood, i.e., the transport of gases. In human, haemoglobin is localised to the RBC.

The **leucocytes** are the most active and motile constituents of blood, as well as lymph. These cells are colourless because they lack any pigment. The number of WBC in blood has a range of 7000-10000/mm^3. Leucocytes are of different types and these are broadly grouped into two categories :

(i) **granulocytes**, and
(ii) **agranulocytes**.

Granulocytes are the cells containing granules, and a polymorphic nucleus in the cytoplasm. These are of three types : **neutrophils**, **eosinophils** and **basophils**.

Neutrophils do not take colour when exposed to acidic, as well as basic, dyes. Its nucleus has two to seven lobes. The cell is nearly circular and measures 12-15 μm in diameter. Neutrophils are mainly responsible for protection against infection. This constitutes 62 per cent of total leucocytes.

Eosinophils are characterised by a bilobed nucleus. The cell contains numerous coarse granules that are stained bright red with eosin, an acid dye. The proportion of eosinophils is less than 3 per cent. The eosinophils are not markedly motile and only slightly phagocytic. They play an important role in detoxification.

Basophils are found in least proportion (i.e., 0.5 to 1 per cent). The nucleus has two to three lobes. It contains fewer coarse granules, which can be stained with basic dyes, e.g., methylene blue. Basophils are significant in allergic reactions.

Agranulocytes are leucocytes that lack granule and consist of two types of cells : **lymphocytes** and **monocytes**.

Lymphocytes have a single large nucleus with pale cytoplasm; they have a proportion of about 30 per cent. An important function of the lymphocytes is the manufacture of serum globulin, and they play a key role in immunological reactions. Lymphocytes are of two kinds : *small lymphocyte* and *large lymphocyte*. Small lymphocytes are slightly larger than the red cells and about 7–10 μm in diameter. The nucleus is relatively large, and stains more deeply with basic dyes than the surrounding narrow rim of cytoplasm that separates it from the boundary of the cell. Large lymphocytes are considerably larger (10-14 μm in diameter) and the cytoplasm is more abundant.

Monocytes are large cells (10-18 μm in diameter) with kidney-shaped nucleus. These constitute 5-6 per cent of total WBC. They are actively motile and are phagocytic.

Thrombocytes or **platelets** are small (2-4 μm in diameter), round or oval cells. Their number in blood ranges between 2,50,000 to 4,00,000/mm^3. They play an important role in blood coagulation. At the site of injury of the blood vessels, sufficiently large number of platelets accumulate and release the platelet factor, which results in blood coagulation.

Human Heart

Like all the vertebrates, the human heart is mesodermal in origin. It is a hollow and muscular structure situated behind the sternum and between the lungs in the thoracic cavity, with its apex resting on the diaphragm. It looks like a blunt cone, which is 12 cm in length and 9 cm in width at the broadest point (Fig. 7.4). Its narrow apex is directed downward and to the left.

Heart remains enclosed in double-walled sac, called **pericardium**, consisting of an outer non-distensible fibrous layer and an inner serous layer. In between the two layers, there is a very narrow space, called the pericardial cavity, which is filled with pericardial fluid. This fluid keeps the surface of the heart moist and prevents it from friction between the heart walls and surrounding tissues.Human heart consists of four chambers : two upper thin-layered **atria** (*sing. atrium*) and two lower thick-layered **ventricles**. The atria are situated at the broader end, while the ventricles are situated at the lower conical end. Externally, a transverse groove is present between the atria and ventricles, called the **coronary sulcus**. On the ventricle, also two grooves are present, which are called the

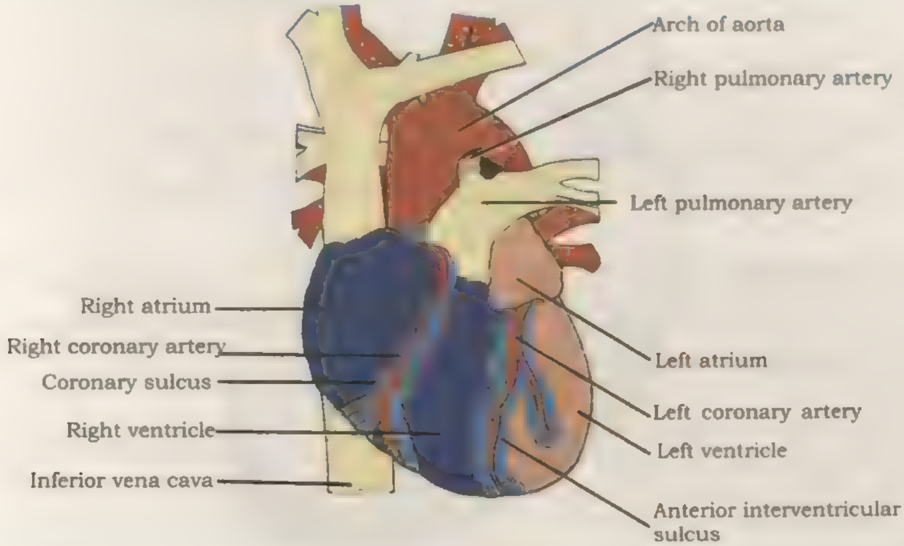


Fig. 7.4 External features of human heart

anterior interventricular sulcus and **posterior interventricular sulcus**. These sulci house coronary arteries, through which the heart receives blood. The right and left atria receive blood from different body parts. The right atrium receives deoxygenated blood from all parts of the body, except the lungs, through the superior and inferior vena cava. Pulmonary veins bring oxygenated blood to the left atrium from the lungs. The right and left atria pump the blood into the right and left ventricles, respectively. From the right ventricle arises a pulmonary trunk, which soon bifurcates to form right and left pulmonary arteries, which supply deoxygenated blood to the lungs of the respective side. The left ventricle gives rise to an ascending aorta, from which the oxygenated blood is supplied to the coronary arteries and the systemic circulation of the body.

Internally, the four chambers are separated by septa and valves (Fig. 7.5). The right and left atria are separated by inter atrial septum. An oval depression is present on this septum, called as **fossa ovalis.** It represents the remnant of **foramen ovale** (an opening in the interatrial septum of the foetal heart). The two ventricles are similarly separated by interventricular septum. The wall of the heart is made up of cardiac muscle fibres, connective tissue and tiny blood vessels.

There are a number of valves present between the chambers of the heart. These valves regulate the direction of flow of blood. **Atrioventricular** (AV) **valves** separate the atria and ventricles. The right AV valve lies between right atrium and right ventricle. It is otherwise known as the **tricuspid valve** because it consists of three flaps or cusps. The pointed ends of the flaps are projected towards ventricle. These are attached to the wall of the ventricle through tendon-like cords, called **chordae tendinae**. The left AV valve is formed of two cusps; it is called the **bicuspid** or **mitral valve**. The major arteries, that leave the heart, have semilunar valves, which prevent the back flow of blood into the ventricles. The pulmonary **semilunar valve** guards the

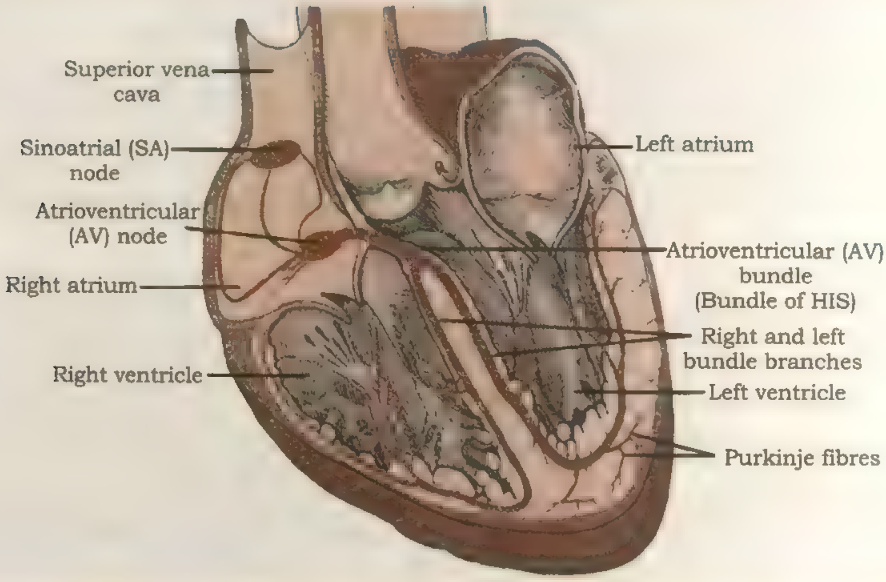


Fig. 7.5 *SA node, AV node and bundle of fibres in human heart*

opening in the right ventricle, from where the pulmonary trunk begins. Similarly, the **aortic semilunar valve** guards the ascending aorta. Besides, the openings of superior, as well as inferior, vena cava are present in the right atrium and pulmonary veins in the left atrium.

Pumping action of human heart : Heart is a complex pumping organ, which receives blood from different parts of the body in its atria and pumps it to the various body parts from ventricles.

Heart muscles continuously generate impulses in a manner that causes rhythmic contraction and relaxation of the heart chambers in a specific sequence. In normal conduction of impulse, the atrial contraction precedes that of the ventricle. For the purpose of maintenance of the heart-rhythm, a highly specialised excitatory and conductive system is present, which includes sino-atrial node (SA node), internodal pathways, the atrio-ventricular node (AV node), the AV bundle and the bundle of purkinje fibres.

The **SA node** (Fig. 7.5) is a small, flattened and ellipsoid strip of muscle fibre of 3 mm size, situated in the upper lateral wall of the right atrium. The fibres arising from it remain in direct contact with the fibres of the atria. The fibres of the SA node express the ability of self-excitation and control the rate of entire heartbeat. The fibres of SA node have high concentration of sodium ion in the extra-cellular fluid and negative charge inside the nodal fibres. Due to this high concentration and presence of open channel, sodium ions always tend to enter inside. This results in the rise of membrane potential and the generation of the action potential, causing the excitation of the SA node. The fibres of the **sinus node** remain closely associated with the muscles of auricles. Due to this the action potential generated at SA node very soon travels throughout the auricles at a velocity of 0.3 m/sec. This, ultimately, stimulates the **AV node** through internodal pathway, which is present in the posterior wall of the septum of the right atrium. From the AV node, two specialised muscle

fibres (left and right), called **bundle branches**, originate and run into wall of the left and right ventricle. The bundle branches continue as myocardial fibres and spread throughout the ventricular wall. These fibres are called **purkinje fibres**. The impulse travels all along the ventricles via these bundle branches. This conduction is organised in such a way that, there is a delay in transmission of impulse from SA node to the ventricles.

The sequence of events, which occur from the beginning of one heartbeat to the beginning of the next (completion of one heart beat), is called **cardiac cycle.** During the cardiac cycle, blood flows through the cardiac chambers in a specific direction. In the cardiac cycle, the phase of contraction is called **systole**, and the phase of relaxation is **diastole**. A complete heartbeat consists of a systole and a diastole of both the atria, plus the systole and diastole of both the ventricles. The pumping action during single cardiac cycle involves following steps :

(i) ***Atrial systole*** : Under normal conditions, blood continuously enters into right atrium through superior, as well as inferior, vena cava and coronary sinus. The pulmonary veins bring blood to left atrium from lungs. From the atria, nearly 70% of the blood passively flows into the ventricles. Rest of the blood is pumped into the ventricle by the contraction of atria. The arrangement of valve is such that it allows the flow of blood from atria to ventricles.

(ii) ***Ventricular filling*** : As soon as the atrioventricular valves open, nearly one-third of the ventricle is filled. Rest of the ventricular filling takes place during the contraction of the atria.

(iii) ***Ventricular systole*** : When the atrial systole approaches its end, the action potential passes from SA node to the AV node, as well as the ventricles. Consequently, the ventricles contract which results in the rise of ventricular pressure, and both the atrioventricular valves are closed to prevent the back flow of blood. The contraction of ventricles is so strong that the ventricular pressure exceeds the aortic pressure, as a result of which, the semilunar valves open. Now, the blood is pumped into the pulmonary trunk and aorta.

(iv) ***Ventricular diastole*** : The ventricular systole is followed by ventricular diastole, during which, there is a fall in ventricular pressure. The semilunar valves close to prevent back flow of blood. At the same time, the AV valve opens to allow the flow of blood from both the atria to the respective ventricles.

Heart Beat and Pulse

The human heart beats at the rate of about 72-80 per minute in the resting condition. A complete heartbeat consists of both systoles and diastoles of atria and ventricles. As a result, a wave of distention passes along the arteries, immediately after a ventricular systole. This wave of distention is called **arterial pulse**. It can be felt by placing a fingertip on the artery near the wrist. This artery palpitates at a rate corresponding to that of heartbeat. Thus, pulse rate increase during exercise, fever and emotional and psychological excitements.

Heart sound **:** The rhythmic closure and opening of the valves cause the **sound** of the heartbeat during the cardiac cycle. The first sound (*lubb*), which is of longer duration (0.16-0.90 sec) and a louder one, is created by the closure of the atrioventricular valves immediately after the start of the ventricular systole. The second sound (*dubb*) is of shorter duration (0.10 sec), and is created by the closure of the semilunar valve at the end of the ventricular systole. There is a gap or pause between this second sound and the first sound of the next cardiac cycle. This pause is nearly twice as long as the pause between first and second sound of one cycle. The pause between the end of the second sound and the beginning of the first sound coincides with ventricular diastole.

Blood Vessels and Course of Circulation of Blood

The blood flows strictly through a fixed route through the arteries and veins. Basically, each artery and vein consists of three layers : an inner lining of squamous endothelium, the **tunica intima**, a middle layer of smooth muscle and elastic fibres, the **tunica media**, and an external layer of fibrous connective tissue with collagen fibres, the **tunica externa**. The tunica media is comparatively thin in the

veins. Arteries carry blood away from the heart, whereas veins carry blood toward the heart. These are so perfectly coordinated that all the body parts, except the lungs, receive the supply of oxygenated blood. The system of blood vessels that ensures the supply of oxygenated blood from the left ventricle to all the body organs and return of deoxygenated blood to the right atrium, is called **systemic circulation** (Fig. 7.6). The main purpose of such a circulation is to transport oxygen, as well as nutrients to the body tissues, and to remove carbon dioxide and harmful nitrogenous wastes from them. It starts from the aortic arch arising from left ventricle to supply blood away from heart, and terminates as superior and inferior vena cava opening into the right atrium. The aortic arch, before turning downward to form the **abdominal aorta**, gives of three branches that supply blood to the head region and arms. The abdominal aorta caters to the need of visceral organs and lower extremities. The regular oxygenation of the blood returning to right atrium is necessary in order to ensure such a circulation. For this purpose, the circulatory system is associated with the lungs through arteries and veins, which form the pathway of the **pulmonary circulation** (Fig. 7.6). The arteries supply the deoxygenated

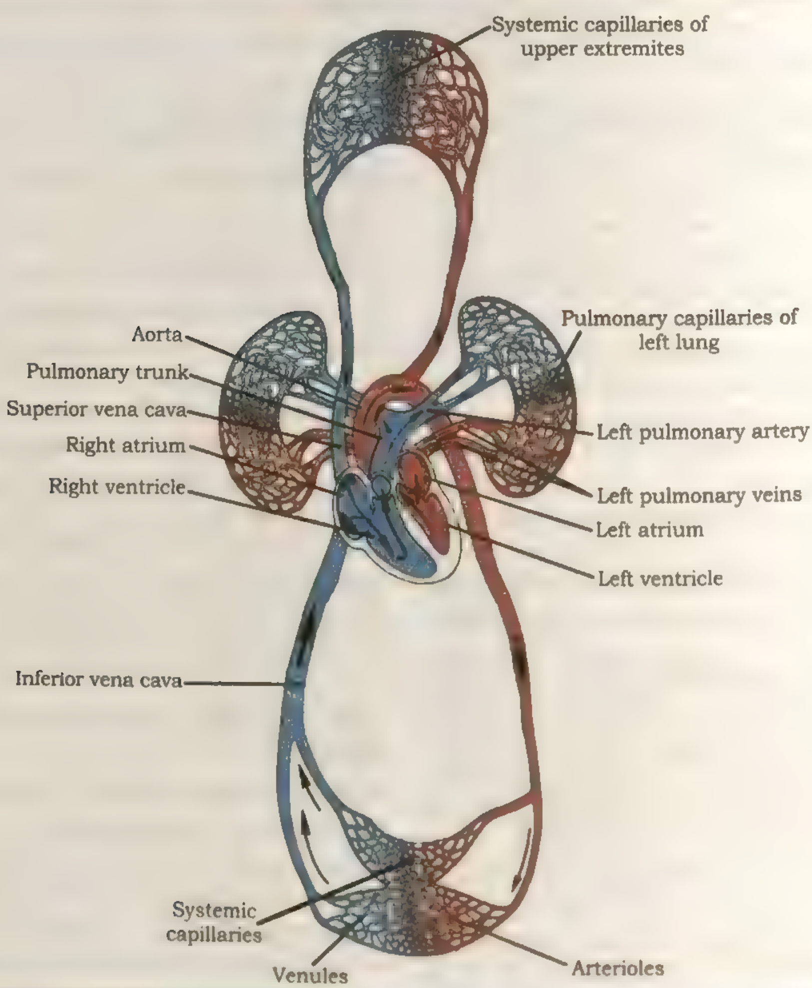


Fig. 7.6 *Pulmonary and systemic circulation*

blood from the right ventricle to the lungs, and veins bring back the oxygenated blood to the left auricle. Besides these two routes of circulation, the supply of blood to the heart muscles (myocardium) is also important. This is ensured by the coronary arteries forming the **coronary circulation**. It is a pathway of the blood through arteries from the aorta arising from the heart and returning to the right atrium.

In some cases, a vein carrying deoxygenated blood from a system of capillaries, divides again into a second capillary system in the tissues before returning to the heart. Such a vein is called a **portal vein**. Together with the capillary system to which it supplies blood, a portal vein constitutes a **portal system**. For example, a hepatic portal vein returns blood from the intestine and breaks into a portal system of capillaries in the liver (hepatic portal system). This enables the liver cells to take up the nutrients from the portal blood brought from the small intestine.

7.4 Lymphatic System

The lymphatic system consists of a network of vessels and lymph organs, like lymph nodes, bone marrow, spleen and thymus (Fig. 7.7). The fluid present in the lymphatic system is called **lymph**. Lymph is a transparent fluid derived from blood and other tissues, which accumulates in the interstitial spaces as the interstitial fluid. Lymph contains leucocytes, mainly the lymphocytes. This fluid has a composition similar to that of plasma, except that it is low in protein. Fine channels present in the tissue, transport a portion of this interstitial fluid. These channels are called **lymph vessels**. Structurally, the lymph vessels are similar to that of veins, except for their thinner wall and more valves. Besides, a number of **lymph nodes** are present at intervals. These structures are made up of lymphoid tissues lying on the lymphatic vessels in which the foreign bodies (antigens) are filtered and destroyed by the lymphocytes. The lymphatic vessels, form blind-ended capillaries in the

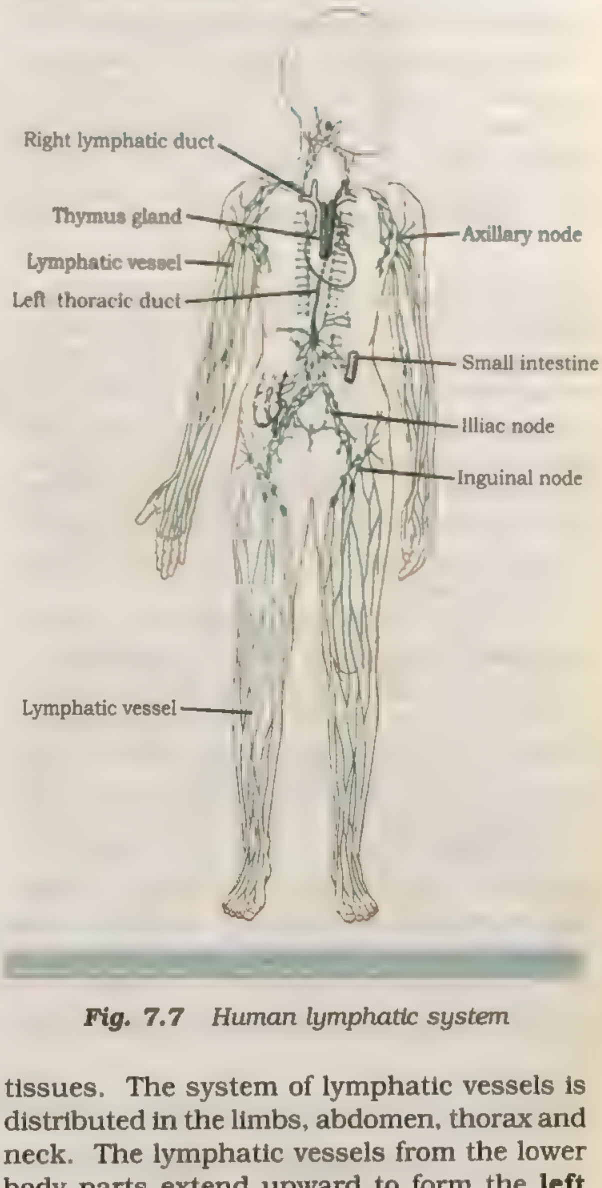


Fig. 7.7 Human lymphatic system

tissues. The system of lymphatic vessels is distributed in the limbs, abdomen, thorax and neck. The lymphatic vessels from the lower body parts extend upward to form the **left thoracic duct,** which receives the vessels from left arm, left side of head, and partly from thoracic region. This thoracic duct opens into the vein near the junction of left internal jugular vein and the subclavian vein. The lymphatic vessels from the right arm, the remaining thoracic parts, and the right side of the head, form the **right lymphatic duct**, which opens at the junction of right subclavian and internal jugular vein. Thus, the lymphatic system provides an accessory

route for the flow of interstitial fluid into the blood. The lymphocytes present in the lymphatic system play important role in the defence against foreign agents or microbes. You will learn in detail about this defence mechanism or immune system of humans in Chapter 25.

7.5 Electrocardiogram

The passage of cardiac impulse through the heart spreads electrical current into the tissues around the heart, and a small portion spreads throughout the surface of the body. These electrical changes can be recorded all along the cardiac cycle. The recording of electrical potential generated by the spread of cardiac impulse, is called **electrocardiogram** (ECG). In fact, ECG is a graphic record of the electric current produced by the excitation of the cardiac muscles.

A normal electrocardiogram (Fig. 7.8) is composed of a P wave, a QRS complex and a T wave. The QRS complex has three separate Q, R and S waves. The P wave is a small upward wave that indicates the depolarisation of the atria, or the spread of impulse from the sinus node throughout the atria. The second wave, i.e., the QRS complex, begins after a fraction of a second of the P wave. It begins as a small downward deflection (Q), and continues as large upright (R) and triangular wave, ending as downward wave (S) at the base. This is the expression of the ventricular depolarisation. The potential generated by the recovery of ventricle from the depolarisation state is, called the **repolarisation wave**.

In electrocardiography, P-Q interval (also called PR interval) is the time taken by the impulse to travel through atria, AV node and the rest of the conducting tissues. During rheumatic fever, and in arteriosclerotic heart disease (i.e., the formation of plaques and calcification), the P-Q interval lengthens. This is due to the inflammation of atria and atrioventricular node. The normal PQ interval lasts for 0.16 second. The enlarged Q and R waves are the indication of myocardial infarction. The ST interval is the representation of time between the end of the spread of impulse through ventricles, and its repolarisation. The S-T segment is elevated in acute myocardial infarction, and depressed in a condition when the heart muscles receive insufficient oxygen. The ventricular repolarisation is represented as T wave. When the heart muscle receives insufficient oxygen, then the T wave is flattened.

For the purpose of recording, metal electrodes or leads are attached in each arm and leg with the help of straps after cleaning and putting a special jelly, which improves electrical conduction. An additional electrode is placed on the chest with the help of a rubber suction cup. Then, the electrocardiograph is switched on. The electrical current of the heart is detected and amplified by the machine, and

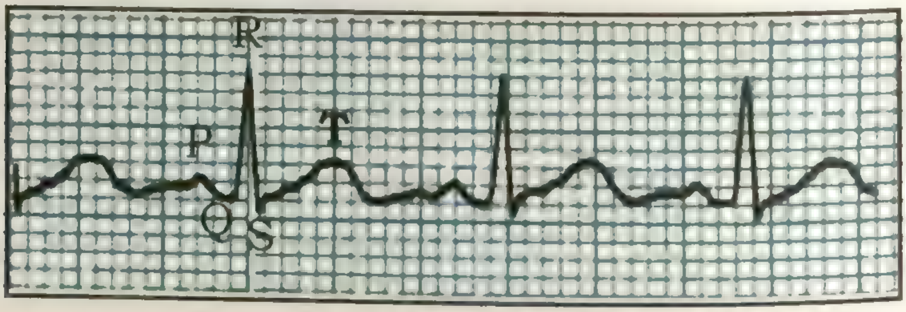


Fig. 7.8 Normal ECG

it is transmitted to the recording pen that draws a wavy line, called the **deflection waves** (electrocardiogram).

7.6 Pacemaker

During the pumping action of the heart, the atria and the ventricles contract rhythmically. The impulse of this wave of contraction begins every time from the SA node (sinus node) present in the right atrium. Thus, it can be said that SA node controls the heartbeat, and hence, it is the **natural pacemaker** of the heart. Pacemaker, in fact, is the rhythmic centre, which establishes a pace of activity. Sometimes, the component of the impulse conduction system is disrupted, causing irregularity in the heart rhythm, like failure of receiving the atrial impulse by ventricle or completely independent contraction of the atria and the ventricles. Such types of patients are provided with an artificial electronic device, which regularly sends small amount of electrical charge for maintaining the rhythmicity of the heart. This device is known as **artificial pacemaker**, which is implanted subcutaneously in the upper thoracic region having a connection with the heart. The artificial pacemaker consists of a pulse-generator containing cell (solid state lithium cell) to produce electrical impulse, the lead in the form of a wire, which transmits the impulse and an electrode, which is connected to the portion of the heart where impulse is to be transmitted.

7.7 Disorders Related to the Circulatory System

Any kind of abnormal condition, either in the circulatory system or in the heart, may affect the overall physiology. Very often, it is expressed as one or the other kind of disease. A few of such diseases are as follows :

Hypertension : It is a manifestation of increase in the blood pressure of a person. The normal arterial systolic and diastolic pressure of a healthy individual is 120 mm Hg and 80 mm Hg, respectively. Under various physiological conditions, moderate level of fluctuation may occur. But the increase in the blood pressure beyond 140 mm Hg (systolic) and 90 mm Hg (diastolic), is referred to as high blood pressure. Its degree may vary from mild to high. A continuous or sustained rise in the arterial blood pressure is known as **hypertension**. High blood pressure can potentially harm the three vital organs, i.e., heart, brain and kidneys. High blood pressure compels the heart to work excessively, due to which the congestive heart disease may set in at an early age. In brain, it can cause haemorrhage, or infarctions, leading to various disabilities. In the long-run, it also affects kidneys, leading to renal failure.

Atherosclerosis : It refers to the deposition of lipids (specially cholesterol) on the walls lining the lumen of large and medium sized arteries. Such a deposition is called **atheromatous** or **atherosclerotic plaque**. Its formation starts with the deposition of minute cholesterol particles/ crystals in the **tunica intima** and smooth muscles. Gradually, these plaques grow due to the proliferation of the fibres and small muscles around it. This results into the reduction of the lumen size of the artery, and consequently, the flow of blood is also reduced. In extreme circumstances, these plaques may completely block the artery. Such plaques, if formed in the coronary artery, reduce the blood supply to the heart, or may stop the supply due to complete blockage. This may result in heart attack or stroke.

Arteriosclerosis : It refers to the hardening of the arteries due to deposition and thickening. In the case of arteriosclerosis, calcium salts precipitate with the cholesterol forming plaque. This calcification of the plaques, ultimately makes the wall of the arteries stiff and rigid, and is referred to as the 'hardening of the arteries'. Such an affected artery loses the property of distension, and its walls may rupture. The blood leaking from the ruptured wall may clot and block the pathway of blood flow. Such a thrombosis or clot formation in the coronary artery, may lead to a heart attack and even death.

SUMMARY

The body fluid or blood that circulates in the body, requires supply of nutrients and oxygen. It also removes the harmful waste from tissues. Almost all the animals possess some mechanism for circulation of body fluid. Blood or the body fluid may circulate open in the body cavity or in vessels.

Cockroach exhibits open circulation of hemolymph through different sinuses present in the body. It also possesses a tubular heart that regulates the circulation.

In humans, blood flows through the arteries and veins and the muscular heart acts as a pumping organ. Blood consists of plasma, RBC, WBC and platelets. Human heart has four chambers, comprising two atria and two ventricles. The left part of the heart receives oxygenated blood from the lung and pumps it to the different body parts. The right part of the heart receives the deoxygenated blood from different parts of the body and pumps it to the lungs for oxygenation. This is called double circulation.

Heart contracts and relaxes rhythmically to pump blood. Sino-atrial node, atrioventricular node and their fibres regulate the rhythm of hearts. Besides the blood vascular system, another channel of vessels, called the lymphatic system, is also present, which carries the tissue fluid to circulating blood. This system is also related to the immune response of the body.

The electrical activity of heart can be graphically represented by ECG, which shows different waves. Pacemaker is a device, which regulates the rhythmicity of heart.

Hypertension is expressed as high blood pressure, and it is one of the common disorders related to blood circulation. Atherosclerosis and arteriosclerosis cause blocking of the artery, resulting into insufficient flow of blood. It may cause heart attack.

EXERCISES

1. What is blood? Describe its components.
2. Describe the structure of human heart.
3. Write the differences between :
   (a) Blood and haemolymph
   (b) Open and closed system of circulation
4. Describe circulatory system of cockroach.
5. What is the heart rhythm? Discuss.
6. Define the terms :
   (a) SA node
   (b) Systole
   (c) Diastole
   (d) Pulmonary circulation.
7. What is electrocardiogram? Write about its significance.

8. Match Column I with Column II :

	Column I		Column II
(i)	Haemolymph	(a)	Coagulation
(ii)	RBC	(b)	Immunity
(iii)	Antibody	(c)	Cockroach
(iv)	Platelets	(d)	Contraction
(v)	Systole	(e)	Gas transport
		(f)	Hypertension

9. Write true or false :
   (a) Atrioventricular node is natural pacemaker of heart.
   (b) Human heart has inter-auricular foramen.
   (c) Heart of cockroach is segmentally arranged.
   (d) Right atrioventricular valve is a semilunar valve.
   (e) Normal systolic and diastolic pressure of humans is 120 and 60 mm Hg, respectively.

10. What is hypertension? What are its causative factors?

11. What is lymphatic system? Discuss its importance.

12. Fill in the blanks :
   (a) Eosinophil is ________________ .
   (b) Pulmonary artery carries ________________ blood.
   (c) Heart of cockroach is present in the ________________ sinus.
   (d) Platelets help in ________________ .
   (e) Haemoglobin is present in ________________ .

13. What is an artificial pacemaker? Explain.

14. How is arteriosclerosis different from atherosclerosis? Discuss.

15. What is lymph node?

16. What is systemic circulation?

17. Describe the importance of pulmonary circulation.

Osmoregulation and Excretion in Animals

Maintenance of **homeostasis** or the steady state is an utmost necessity for normal life processes. Homeostatic mechanisms maintain conditions within a range, in which the animal's metabolic processes can occur. Moreover, the cells of an animal cannot survive even a change in water content beyond the range. Therefore, animals, whether they inhabit land, or freshwater, or marine, or migrate between these environments, have an impervious coat to resist water entry or exit, for example, scales are present in fish and reptiles, feathers in birds and hairs in mammals. However, all possess readily permeable membranes, such as respiratory surfaces (lungs, trachea, gill) and oral membranes. These surfaces can neither be waterproof, nor can resist ionic diffusion. Similarly, accumulation of toxic metabolic wastes in the cellular environment is dangerous. In this chapter, you will learn about regulation of solute and water movements in animals. Also, you will gather information about the mechanism of removal of nitrogenous products of metabolism.

8.1 Osmoconformers and Osmoregulators

The regulation of solute movement, and hence, water movement, through osmosis, is known as **osmoregulation**. **Osmosis** may be defined as a type of diffusion where the movement of water occurs selectively across a semipermeable membrane. It occurs whenever two solutions, separated by semipermeable membrane (the membrane that allows water molecules to pass but not the solutes) differ in total solute concentrations, or **osmolarity**. The total solute concentration is expressed as molarity or moles of solute per litre of solution. The unit of measurement for osmolarity is milliosmole per litre (mosm L^{-1}). If two solutions have the same osmolarity, they are said to be **isotonic**. When two solutions differ in osmolarity, the solution with higher concentration of solute is called **hypertonic**, while the more dilute solution is called **hypotonic**. If a semipermeable membrane separates such solutions, the flow of water (osmosis) takes place from a hypotonic solution to a hypertonic one.

Osmoconformers are the animals that do not actively control the osmotic condition of their body fluids. They rather change the osmolarity of body fluids according to the osmolarity of the ambient medium. All marine invertebrates and some freshwater invertebrates are strictly osmoconformers. Hagfish is the vertebrate osmoconformer. Osmoconformers show an excellent ability to tolerate a wide range of cellular osmotic environments.

Osmoregulators, on the other hand, are the animals that maintain an internal osmolarity, different from the surrounding medium in which they inhabit. Many aquatic invertebrates are strict or limited osmoregulators. Most vertebrates are strict osmoregulators, i.e., they maintain the composition of the body fluids within a narrow osmotic range. The notable exception, however, are the hagfish (*Myxine* sp., a marine cyclostome fish) and elasmobranchs (sharks and rays).

Osmoregulators must either eliminate excess water if they are in a hypotonic medium, or continuously take in water to compensate

for water loss if they are in a hypertonic situation. Therefore, osmoregulators have to spend energy to move water in or out and maintain osmotic gradients by manipulating solute concentrations in their body fluids.

Water and Solute Regulation in Freshwater Environment

Osmolarity of freshwater is generally much less than 50 mosm L^{-1} while the freshwater vertebrates have blood osmolarities in the range of 200 to 300 mosm L^{-1}. The body fluids of freshwater animals are generally hypertonic to their surrounding environment. Therefore, freshwater animals constantly face two kinds of osmoregulatory problems : they gain water passively due to osmotic gradient, and continually lose body salts to the surrounding medium of much lower salt content.

However, the freshwater animals prevent the net gain of water and net loss of body salts by several means. Protozoa (*Amoeba*, *Paramoecium*) have contractile vacuoles that pump out excess water. Many others eliminate water from the body by excreting large volume of very dilute urine. As a general rule, animals living in freshwater, including freshwater fish, do not drink water to reduce the need to expel excess water. In these animals, water uptake and salt loss are minimised by a specialised body covering (subcutaneous fat layer of scaleless fish and scales over the body of fish or crocodile). Freshwater animals have remarkable ability to take up salts from the environment. The active transport of ions takes place against the concentration gradient. Specialised cells, called *ionocytes* or *chloride cells* in the gill membrane of freshwater fish can import Na^+ and Cl^- from the surrounding water [Fig. 8.1(a)].

Water and Solute Regulation in Marine Environment

Sea water usually has an osmolarity of about 1000 mosm L^{-1}. Osmolarity of human blood is about 300 mosm L^{-1}. The osmoregulatory problems in marine situation are opposite to those in freshwater environment. Marine bony fish have the body fluids hypotonic to seawater, and thereby, they tend to lose water from the body through permeable surfaces (gill membranes, oral and anal membranes). To compensate for the water loss, marine bony fish drink seawater. However, drinking seawater results in a gain of excess salts. The ionocytes or chloride cells of the gill membrane of marine bony fish help to eliminate excess monovalent ions from the body fluid to the seawater. Divalent cations are generally eliminated with faeces. Hilsa, salmon and other fish that migrate between seawater and freshwater, when in ocean, drink and excrete excess salt through the gill membrane [Fig. 8.1(b)]. A number of hormones play a key role in this switching over process.

In general, the body fluids of marine invertebrates, ascidians and the hagfish are isosmotic to seawater. In elasmobranchs (sharks and rays) and coelacanths (lobe fin fish), osmolarity of the body fluids is raised by accumulating certain organic substances (osmolytes). Retention of osmolytes in body

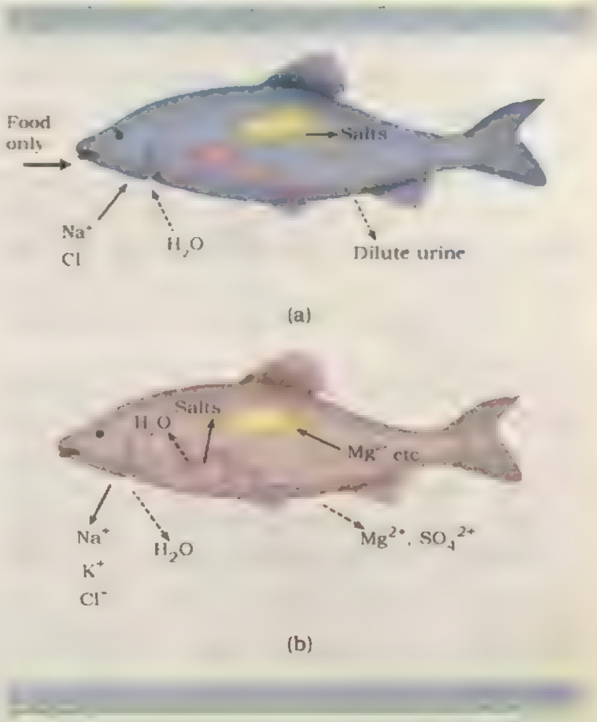


Fig. 8.1 *Water and solute balance in (a) freshwater and (b) marine bony fish*

fluids reduces the osmoregulatory challenges. The best known examples of such organic osmolytes are *urea* and *trimethylamine oxide* (TMAO). Body fluids of sharks and coelacanths are slightly hyperosmotic to seawater due to retention of urea and TMAO while hypoionic to seawater as they maintain far lower concentration of inorganic ions in the body fluids.

Water and Solute Regulation in Terrestrial Environment

Land animals are always subject to osmotic desiccation, like the marine animals. Air-breathing animals constantly lose water through their respiratory surfaces. However, animals utilise various means to minimise this water loss. Good examples are the waxy coatings of the exoskeletons of insects, the shell of the land snails and the multiple layers of dead, keratinised skin cells covering most terrestrial vertebrates. Despite such protective measures, a considerable amount of water is lost through oral, nasal and respiratory surfaces. This may even be fatal for the animal concerned. Humans, for example, die if they lose around 12 per cent of the body water. Therefore, water loss must be compensated by drinking and eating moist food. Desert mammals are well adapted to minimise water loss. Kangaroo rats, for example, lose so little water that they can recover 90 per cent of the loss by using metabolic water (water derived from different cellular metabolic processes). The nasal countercurrent mechanism for conserving respiratory moisture is also important. Behavioural adaptations, such as nervous and hormonal mechanisms that control thirst, are important osmoregulatory mechanisms in terrestrial animals. Many desert animals are nocturnal to avoid the heat of day-time, another important behavioural adaptation that minimises dehydration. The camels, however, reduce the chance of overheating by orienting to give minimal surface exposure to direct sunlight. They produce dry faeces and concentrated urine. When water is not available, the camels do not produce urine but store urea in tissues and solely depend on metabolic water. When water is available, they rehydrate themselves by drinking up to 80 litres of water in 10 minutes. Table 8.1 gives a comparative account of gain and loss of water in humans and kangaroo rats.

Table 8.1 : Water Balance in Humans and Desert Kangaroo Rats

		Kangaroo rat	Human
Water gain	Ingested in	0	1500 (60%)
(ml d^{-1})	liquid Ingested	6 (10%)	750 (30%)
	in food Derived	54 (90%)	250 (10%)
	from metabolism		
		60 (100%)	2500 (100%)
Water loss	Evaporation	43.9 (73%)	900 (36%)
(ml d^{-1})			
	Urine	13.5 (23%)	1500 (60%)
	Faeces	2.6 (4%)	100 (4%)
		60 (100%)	2500 (100%)

ml d^{-1} = 1 milli litre per day

8.2 Elimination of Nitrogenous Wastes

Nitrogen-containing wastes are produced from the metabolism of protein and nucleic acids. These waste products are very toxic to cellular environment. The process by which nitrogen-containing waste products of metabolism are eliminated from the body is called **excretion**. The nature of the nitrogen-containing wastes and their excretion varies among the species, depending on the availability of water. Animals mostly excrete excess of nitrogen as ammonia, urea or uric acid (Fig. 8.2).

Ammonotelism

Most teleost fish (modern bony fish), tadpoles and aquatic insects excrete nitrogenous wastes as ammonia. This phenomenon is referred to as **ammonotelism**, and the concerned animals are called **ammonotelic**. Ammonia molecules are readily soluble in water, so they easily cross the membrane barriers. In soft-bodied invertebrates, ammonia diffuses out across the

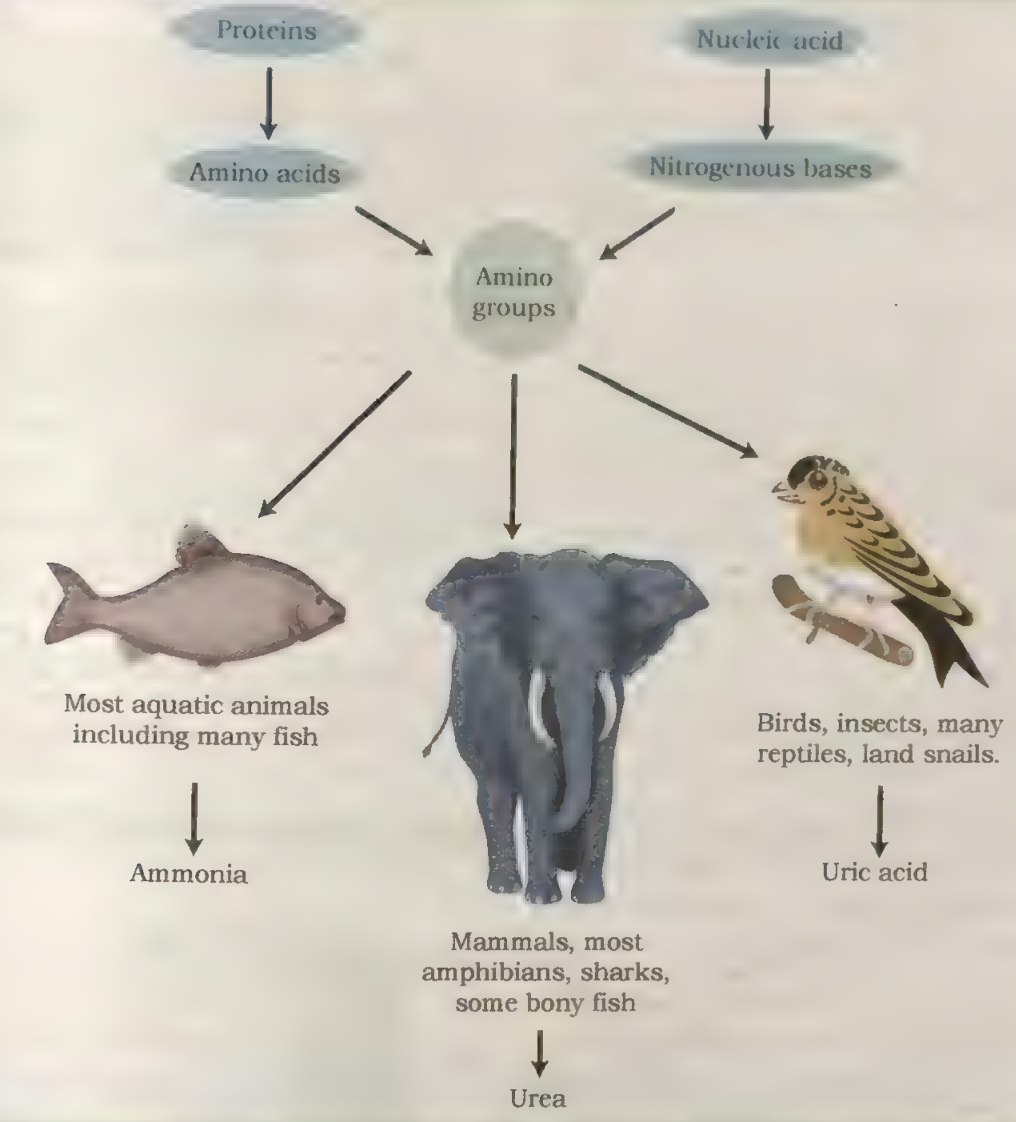


Fig. 8.2 *Major nitrogenous wastes of different animal groups*

whole body surface into the surrounding water. In fish, most of the ammonia (NH_3) is lost as ammonium ions (NH_4^+) across the gill epithelium. Kidneys play a minor role in ammonia excretion.

Ureotelism

Although ammonia excretion works fine in aquatic situation, it is unsuitable for terrestrial situation. Ammonia is very toxic to cellular environment, while urea can be tolerated in a much more concentrated form because it is 100,000 times less toxic than ammonia. For those animals that are under the threat of desiccation, urea excretion or **ureotelism** helps to lose less water while disposing of the nitrogenous wastes. Mammals, most adult amphibians living on land and many marine fish and turtles, which face the problem of

conserving water in their hypertonic environment, are **ureotelic** (excrete urea). Urea is produced in the liver by a metabolic cycle, called **urea cycle** that combines ammonia with carbon dioxide. The circulatory system carries urea to the kidneys for elimination. However, in mammals the total amount of urea produced is not excreted immediately. Instead, some portion of it is retained in the kidneys for osmoregulation. It helps to maintain the osmolarity gradient that functions in water resorption. Sharks also produce urea and retain a good amount of it in the blood as a major osmolyte to balance the osmolarity of the body fluids with the surrounding seawater.

Uricotelism

Uric acid excretion, or **uricotelism**, enables terrestrial animals to excrete nitrogenous wastes of metabolism with a minimum loss of water. Uric acid is thousand times less soluble in water than either ammonia, or urea. It can be excreted as a precipitate after reabsorbing nearly all the water from the urine. Land snails, insects, birds and many reptiles are **uricotelic** and excrete uric acid. In birds and reptiles, urine is eliminated in a paste-like form along with faeces. Uricotelism is particularly advantageous to the land vertebrates those lay shelled eggs. Soluble wastes (like ammonia or urea) can pass out of the shell-less eggs of fish or amphibians, or may be carried away by the mother's blood, as in mammalian embryo. However, the shelled eggs of birds and most reptiles possess many fine pores and are permeable to gases only. Had an embryo produced ammonia or urea within the shelled egg, the soluble nitrogenous waste would have accumulated to the level of toxic concentration. Uric acid, on the other hand, precipitates out of the solution and can be stored in the shell as a solid waste, which is left behind when the animal hatches.

Tadpole and aquatic amphibians excrete ammonia, while their terrestrial adult forms excrete urea. Most terrestrial reptiles excrete uric acid, but crocodiles excrete ammonia in addition to uric acid. Aquatic turtles excrete both urea and ammonia. Some tortoises can even modify their nitrogenous wastes when their environment is changed.

8.3 Simple Tubular Systems

Flatworms (e.g. *Planaria*) have the simplest tubular excretory systems, called **protonephridia**. Rotifers, some annelids, and cephalochordates (e.g. *Branchiostoma*) also possess protonephridia. A protonephridium is a network of closed tubules, the smallest branches of which terminate in cellular unit called **flame bulb** or **flame cell**. The flame bulb has a tuft of cilia projecting into the tubule, and the beating of these cilia drives interstitial fluid along the tubule (Fig. 8.3). The bulb is named flame bulb as the beating of cilia looks like a flickering flame. Collected fluids traverse through the tubular system, and ultimately, pass out of the body through numerous open ends of the tubule, called **excretory pores** or **nephridiopores**, connected to the body surface.

Another type of tubular excretory system also functions in a similar fashion. These

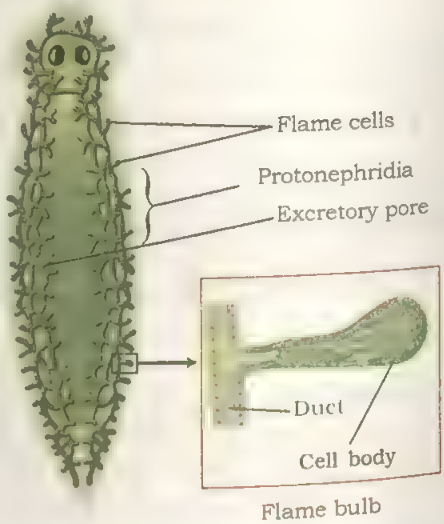


***Fig. 8.3** Protonephridia and flame bulb in Planaria*

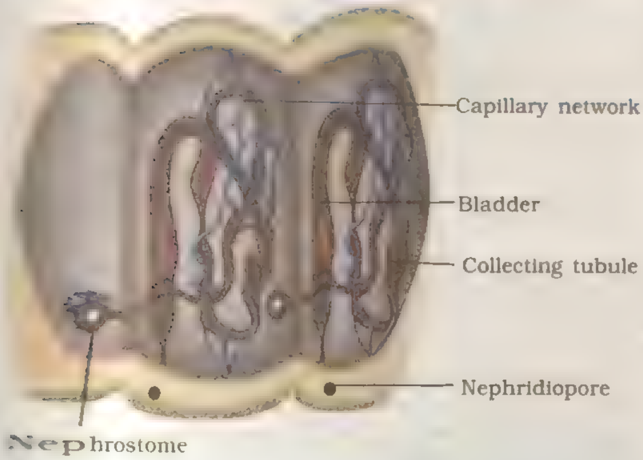


Fig. 8.4 Metanephridia (structure and arrangement) in earthworm

are called **metanephridia** (Fig. 8.4). A metanephridium has internal openings or **nephrostomes** that collect coelomic fluid by the beating of a circlet of cilia present on the margin of the funnel-shaped opening of the tubule. Metanephridia are found in most annelids, including earthworms (Fig. 8.4). Metanephridia have excretory and osmoregulatory functions. As the fluid moves along the tubule, the epithelium lining the lumen pumps essential salts out of the tubule, and the salts are reabsorbed into the blood circulating through capillaries. The urine that comes out through nephridiopores contains nitrogenous wastes and is hypotonic to the body fluids.

Cockroach, and also other insects like grasshopper and locust, have remarkable ability to maintain ionic composition of hemolymph (the blood of insects). The excretory organs, called **malpighian tubules**, open into the alimentary canal at the junction of the midgut and hindgut; their free ends are closed (Fig. 8.5). These tubules remove nitrogenous wastes from the hemolymph and also function in osmoregulation in association with the hindgut. The tubules are long, thin and numerous; they lie bathed in hemolymph. The epithelium that lines a tubule, pumps certain solutes, including salts

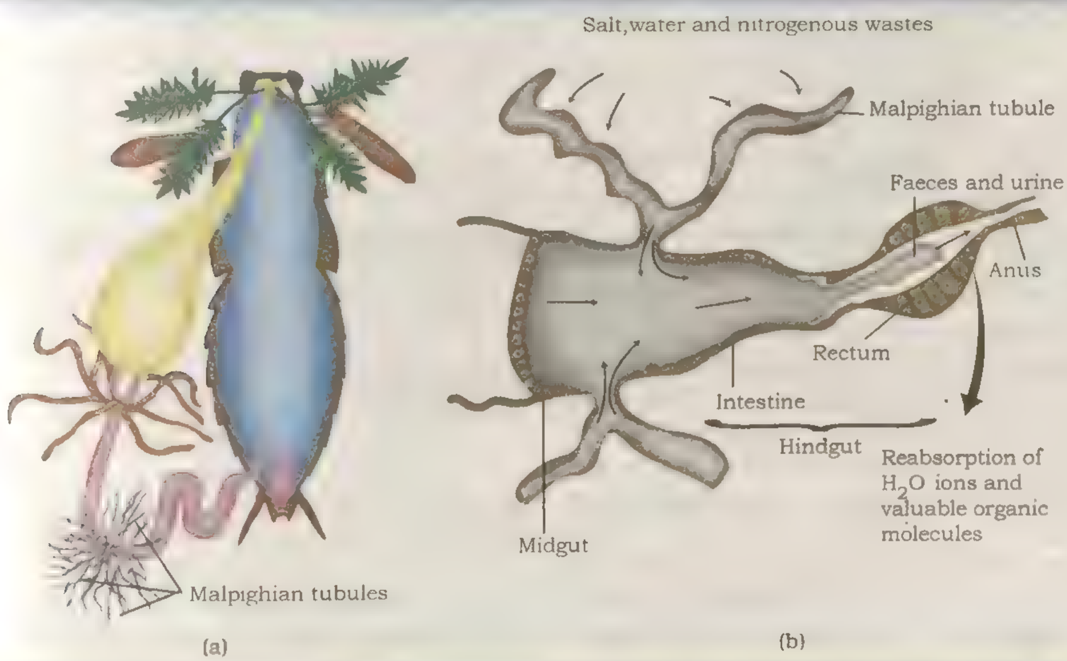


Fig. 8.5 Malpighian tubules of cockroach

MARCELLO MALPIGHI

(1628-1694)

Marcello Malpighi, born in Italy in March, 1628, studied Aristotelian philosophy and graduated as a medical doctor. Malpighi developed an intense interest in scientific research with a fond love of teaching. He is considered as the Founder of comparative physiology.

In 1669, Malpighi published the results of his work on the silkworm. He discovered that these insects had no lungs, but breathed through a row of holes located on the side of their long bodies. Distribution of the air within the insect occurs through a system of tubules that Malpighi termed **trachea**. While observing dissected lung tissue, Malpighi discovered a network of tiny thin-walled microtubules, which he named **capillaries**. He went on to hypothesise that capillaries were the connection between arteries and veins that allowed blood to flow back to the heart. His study of the capillary circulation in man corroborated the insights of William Harvey on circulation. Malpighi's study was published in 1675 by Royal Society of London, England.

He was also the first who systematically and fruitfully exploited the microscope in anatomical and embryological research. He was the first to give an adequate description of the formation of the chick in the egg and he made major contributions to the science of embryology. He produced a series of drawings of the embryo, a revolutionary piece of work at the time because of his important works on anatomy and embryology, including pioneering use of the microscope. A number of anatomical structures still bear his name: Malpighian corpuscles in the circulatory and lymphatic systems, the Malpighian layer of the epidermis (rete Malpighi), and the Malpighian tube in insects. Excretion of nitrogenous wastes, such as uric acid, and water removal from the faeces is carried out by Malpighian tubules.

and nitrogenous wastes, from the hemolymph into the lumen of the tubule. The secretion accumulated in the tubule then passes into the hindgut, where it is dehydrated. This material moves into the rectum and gets voided as concentrated urine through the anus. The epithelium of rectum pumps most of the salt back into the hemolymph, and water follows the salts by osmosis. Thus, after reabsorption of wanted solutes and water, the nitrogenous wastes are eliminated as nearly dry matter along with the faeces.

Most crustaceans have a pair of specialised excretory structures, called **antennal gland** or **green gland**, at the bases of the second antennae. Each antennal gland is made up of a bulbous **endsac** or **coelomosac**, followed by a rounded **labyrinth**. Narrow tubular **nephridial canal** joins the labyrinth and a bladder (Fig. 8.6). Coelomosac is invested with blood

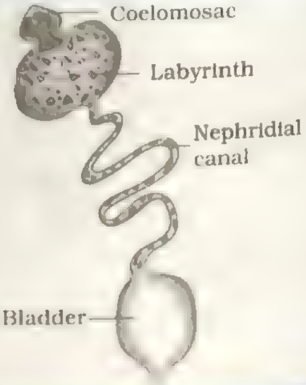


***Fig. 8.6** Antennal gland of crayfish*

lacunae and is the main site of filtration. Urine is first formed in the lumen of coelomosac, which then flows down to the thin, branched and tortuous tubule of the labyrinth. Urine flows from the labyrinth to a large sac-like bladder via the nephridial canal. Coelomosac, labyrinth and nephridial canal are osmotically active. Filtration of the blood at coelomosac produces the initial excretory fluid, which is then modified by selective reabsorption of various substances. Urine is voided from the bladder to the ureter that opens to the exterior at the base of the second antenna.

8.4 Complex Tubular Systems

Human excretory system (Fig. 8.7) consists of two kidneys and their blood supplies, a pair of **ureters**, a **urinary bladder**, and a **urethra.**

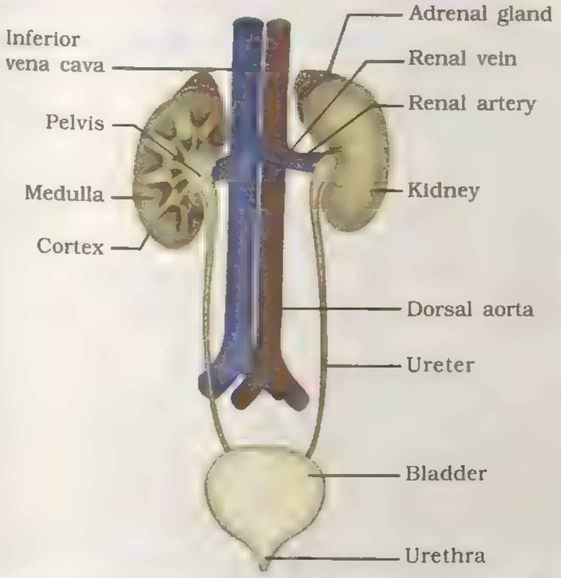


Fig. 8.7 Human urinary system

Each individual normally has two kidneys, one located on each side against the dorsal inner surface of the lower back, at the level of 12^{th} thoracic and 1^{st} or 2^{nd} lumbar vertebrae inside the abdominal cavity. Each kidney is a bean-shaped structure and measures about 10 cm in length, 5 cm in breadth and 3 cm in thickness. In adult, it weighs about 125-170 gm.

A tough, fibrous, connective tissue capsule covers each of the two flattened bean-shaped, dark brown-coloured kidneys. On the concave median margin of the kidney, there is a longitudinal opening, called the **hilum** (**hilus renalis**), through which renal artery and nerves enter and renal vein and ureter leave the kidney. A longitudinal section through kidney shows that the hilum leads to an extensive flat, funnel-shaped space called the **pelvis**. The pelvis is almost completely surrounded by the kidney tissue, which is arranged in an outer functional layer, called the **renal cortex**, and an inner functional layer, called **renal medulla**. Conical pyramid-shaped masses of the renal medulla project into the renal pelvis and are called **medullary pyramids** or **renal pyramids** (Fig. 8.8). The functional units of the

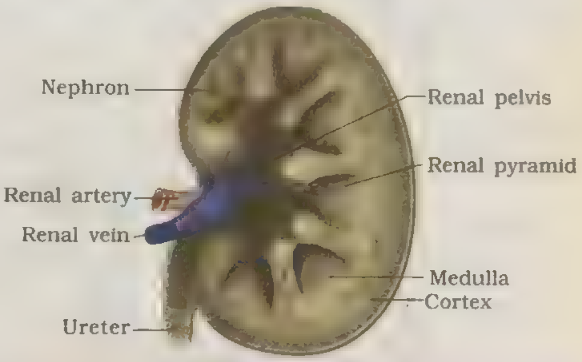


Fig. 8.8 Gross anatomy of human kidney

mammalian kidney, called **nephrons**, are arranged in a radiating fashion within the renal pyramids. Urine produced by each nephron within a renal pyramid empties into collecting duct, which passes through a **papilla** into a **calyx**. The renal calyces drain urine in the central cavity of renal pelvis. Urine passes from the pelvis into the ureter, which takes it to urinary bladder and leaves the bladder during **micturition** (urination) via the membranous duct called urethra, which leads to the end of the **penis** in males, and into the **vulva** in females.

The functional unit of kidney is the nephron (Fig. 8.9), an intricate epithelial tube about 3 cm long and 20-60 μm in diameter. Each kidney contains about one million nephrons, and each nephron can be divided into three main regions :
(i) Proximal nephron : Nephron tubule is closed at its proximal, but open at its distal end. At the closed end, the nephron is expanded and curved inwardly to form the double walled cup-shaped **Bowman's capsule**. The lumen of the capsule is continuous with the narrow lumen that extends through the renal tubule. Within the Bowman's capsule, there is a tuft of capillaries, called **glomerulus**. Glomerulus and its surrounding Bowman's capsule together form the specialised structure – **malpighian corpuscle**. This structure is responsible for ultrafiltration for the first step of urine formation. Highly coiled renal tubule, i.e., proximal convoluted tubule, follows the Bowman's capsule. The epithelial cells of this region are specialised for the transport of salts and other substances from the lumen to the interstitial fluid. The apical membrane of the cells facing the tubule lumen contains numerous microvilli (finger-like projections), which increase the surface area. Mitochondria are concentrated near the basolateral surface, which allows the reabsorption of salts by active transport.

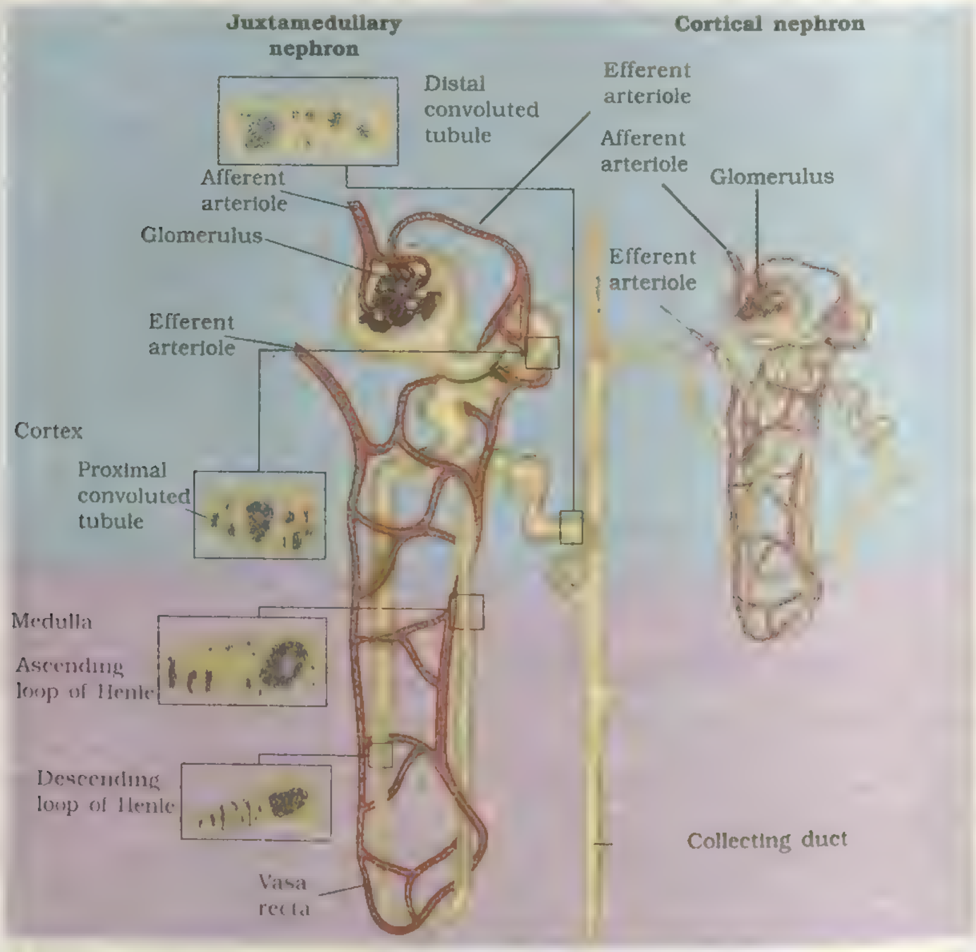


Fig. 8.9 *Structure and position of nephron showing the type of cells lining the nephron tubule*

*(ii) **Loop of Henle*** : It starts at the end of proximal tubule and ends at the beginning of the distal tubule. The hairpin loop comprises a **descending limb** and an **ascending limb**. The first fourth-fifth of the descending limb constitutes the **thick segment** and has the same diameter as that of the proximal tubule. This is also lined by cuboidal epithelium. However, the cells here possess fewer microvilli and mitochondria, compared to the cells of proximal tubule. The distal part of descending limb is the **thin segment** and is lined by flat epithelial cells with sparse microvilli and mitochondria. Ascending limb too, has a thin segment and a thick segment. At the medullary zone, the thin ascending limb widens abruptly and forms thick ascending segment. Cuboidal epithelial cells line this segment.

*(iii) **Distal nephron*** : The ascending limb of the loop of Henle merges into the **distal convoluted tubule**, which joins the **collecting duct**. Each collecting duct receives the ultrafiltrate from many nephrons. This is lined by cuboidal epithelial cells with a few microvilli.

According to the position, nephron can be dividied into two groups (Fig. 8.9) :

(a) *Juxtamedullary nephrons* : Their glomeruli are placed close to the inner margin of the cortex, and long loops of Henle are placed deep into the medulla and are associated with **vasa recta** and peritubular capillaries. The blood first passes through the capillaries of glomerulus, and then, flows through the hairpin loops of the vasa recta of the loop of Henle.

(b) *Cortical nephrons* : These are more common (about 85 per cent of the nephrons) and have their glomeruli in the outer cortex and relatively short loops of Henle that extend a short distance into the medulla. They lack vasa recta but peritubular capillaries are present.

8.5 Mechanism of Urine Formation

Three main processes are involved in urine formation :

*(i) **Glomerular filtration*** : The total volume of blood is filtered through the kidney after every 4.5 minutes. Filtration at the glomeruli forms an ultrafiltrate in the lumen of the Bowman's capsule. An ultrafiltrate of the blood passes through the single cell layer thick capillary walls, through a basement membrane, and finally, another single cell layer thick epithelium of the wall of Bowman's capsule. These three layers together form a sieve-like separation wall between the lumen of the capillary and Bowman's capsule. **Filtration slits** are formed by the assemblages of fine cellular processes of **podocytes** (foot cells). These processes interdigitate, so as to leave very small spaces, the filtration slits, between them. The process of ultrafiltration depends on two main factors : first, the net hydrostatic pressure difference between the lumen of the capillary and the lumen of Bowman's capsule favours filtration, and second, the colloidal osmotic pressure of plasma opposes filtration. The glomerular ultrafiltrate contains essentially all the constituents of the blood, except for blood corpuscles and the plasma proteins. Nearly 15-25 per cent of the water and solutes are removed from the plasma that flows through glomerulus. The **glomerular filtration rate** (GFR) is about 125 ml min^{-1} or about 180 L day^{-1} in human kidneys.

Two important intrinsic mechanisms provide autoregulation of glomerular filtration rate :

(a) *Myogenic mechanism* : An increase in blood pressure will tend to stretch the afferent arteriole, which would be expected to increase the blood flow to the glomerulus. The wall of the afferent arteriole, however, responds to stretch by contraction, thus reducing the diameter of the arteriole, and therefore, increasing the resistance to flow. This myogenic mechanism, thus, reduces variations in flow to the glomerulus in case of fluctuations in blood pressure.

(b) *Juxtaglomerular apparatus (JGA)* : This specialised cellular apparatus is located where the distal convoluted tubule passes close to the Bowman's capsule between the afferent and efferent arterioles (Fig. 8.10). JGA cells secrete enzymes like renin that modulate blood

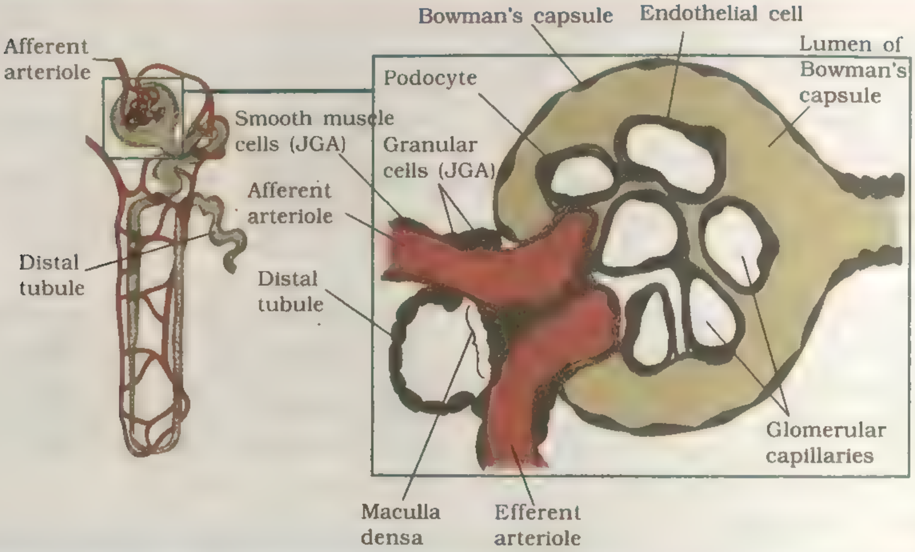


Fig. 8.10 *Location of juxtaglomerular apparatus*

pressure, and thus renal blood flow and GFR are regulated.

Thus, myogenic and juxtaglomerular mechanisms work together to autoregulate the GFR over a wide range of blood pressure. In addition to these, extrinsic neural control also regulates the filtration rate.

(ii) ***Tubular reabsorption*** : As filtration is non-selective, it is important that small molecules essential to the body must be returned to the interstitial fluid and blood plasma. This selective transport of substances across the epithelium of the excretory tubule from the ultrafiltrate to the interstitial fluid, is called **reabsorption**. The proximal and distal convoluted tubules, the loop of Henle and the collecting duct, contribute to reabsorption. Nearly all the sugar, vitamins, organic nutrients and most of the water present in the initial ultrafiltrate are reabsorbed (Fig. 8.11).

(iii) ***Tubular secretion***: Unlike filtration, secretion is a very selective process involving both passive and active transport. As filtrate travels through the nephron tubule, substances that are transported across the tubule epithelium from the surrounding interstitial fluid join it. Because small molecules pass freely from the plasma within the capillaries into the interstitial fluid, the net effect of renal secretion is the addition of plasma solutes to the filtrate within the tubule. The proximal and distal convoluted tubules are the main sites of tubular secretion (Fig. 8.11).

Transport properties of renal tubule : Glomerular filtrate, almost identical to plasma in overall osmolarity and concentrations of small solutes, gradually changes its character as it passes down the renal tubule and becomes urine. Area-specific addition and alterations are as follows :

(a) *Proximal convoluted tubule* : This region of the renal tubule plays an important role in homeostasis by its controlled secretion and reabsorption of several substances (Fig. 8.11). Nearly two-thirds of the NaCl and water in the filtrate are reabsorbed here. This region also helps to maintain a constant pH in body fluids by the controlled secretion of H^+ and by reabsorbing about 90 per cent of the important buffer bicarbonate (HCO_3) from the filtrate. NH_3, drugs and other toxic

substances are secreted into the filtrate in proximal tubule.

(b) *Descending limb of the loop of Henle* : The descending limb is permeable to water but not to salt. Osmotic loss of water from the filtrate, as the descending limb reaches the renal medulla, helps to concentrate NaCl in the filtrate (Fig. 8.11).

(c) *Ascending limb of the loop of Henle* : This section is virtually impermeable to water. This ascending segment is permeable to NaCl. The salt that was concentrated in the filtrate within the descending limb, now passively diffuses out of the ascending limb, contributing to a high interstitial osmolarity in the inner medulla of kidney. Ascending thick segment, too, transfers NaCl from filtrate to interstitial fluid, but here the transport is by active transport (Fig. 8.11).

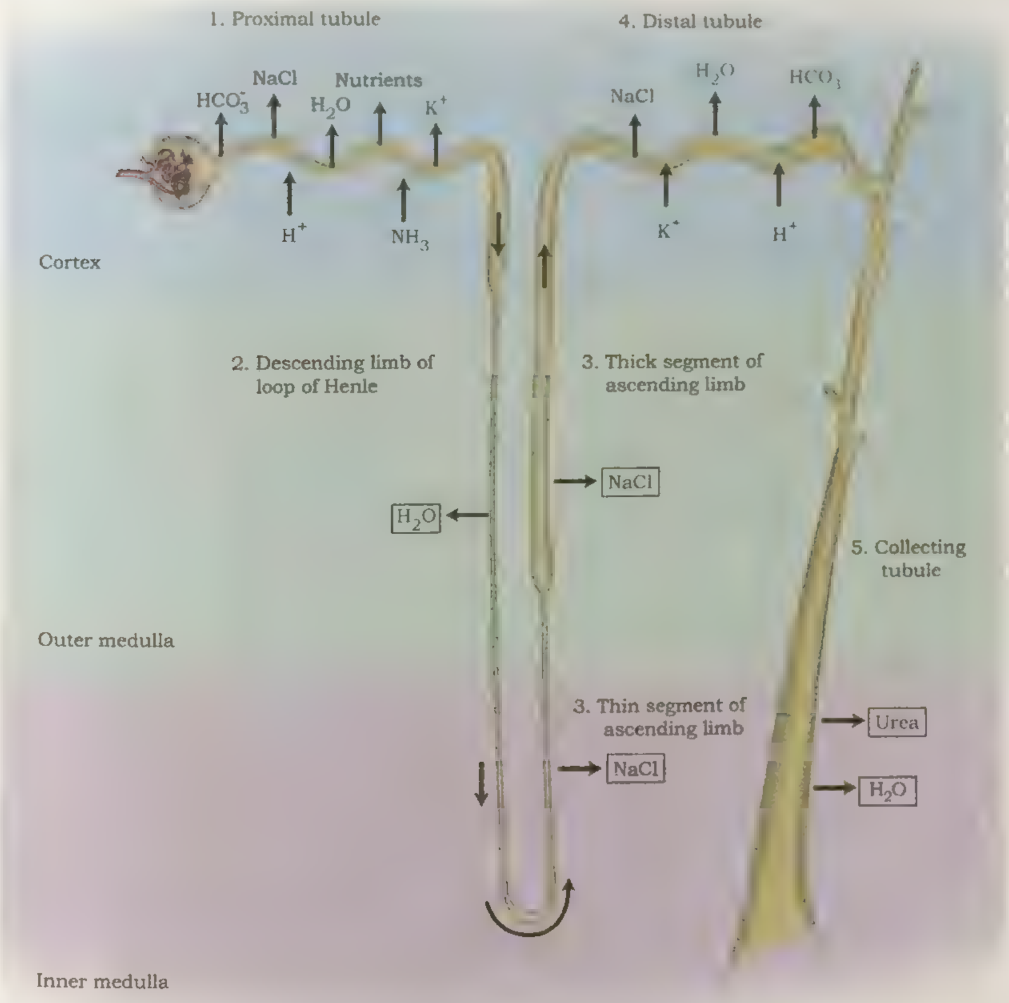


Fig. 8.11 *Filtration, reabsorption and secretion at different parts of the nephron*

(d) *Distal convoluted tubule* : This is another segment of selective secretion and reabsorption. It helps to regulate blood pH by the reabsorption of HCO_3^-, an important buffer. The distal tubule also functions in K^+ and Na^+ homeostasis (Fig. 8.11).

(e) *Collecting tubule* : The specialised cuboidal epithelium of collecting tubule is permeable to water but not to salt in the cortex. This tubule carries the filtrate toward the renal medulla for the second time, and the filtrate becomes more and more concentrated as water is lost to the interstitial fluid (Fig. 8.11). Bottom portion of the collecting tubule is permeable to urea, and leakage of this solute into interstitial fluid contributes to high osmolarity of medulla.

Water conservation and production of concentrated urine :

The loop of Henle is largely responsible for concentrating urine. It is found that the greater the ability of an animal to excrete hypertonic urine, the longer are the Henle's loops in its

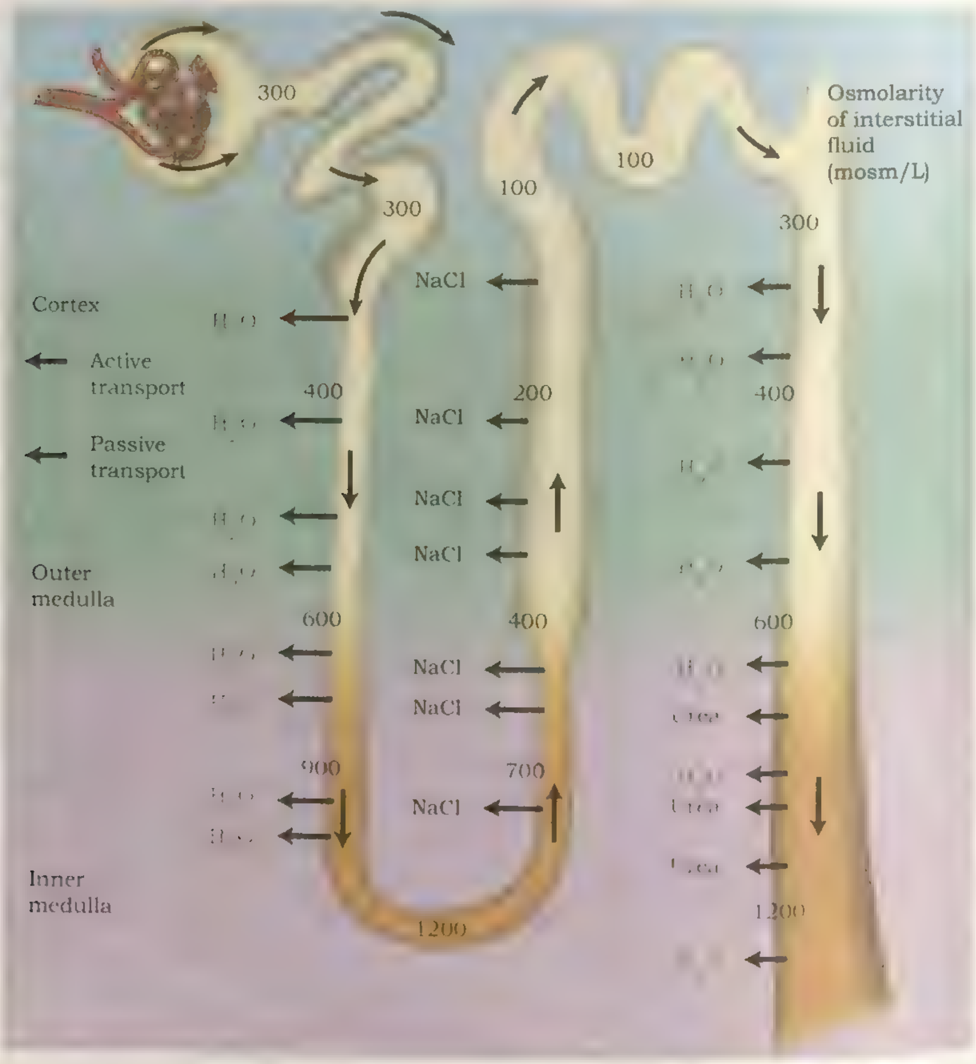


Fig. 8.12 Water conservation and production of concentrated urine in renal tubule

kidneys. Another factor in the question of concentration of urine is the presence of blood vessels, called vasa rectae, in the kidneys. The vasa rectae are in the form of loops. Therefore, the blood flows in opposite directions in the two limbs of each vasa recta; the blood entering its descending limb comes into close contact with the outgoing filterate in the ascending limb of loop of Henle. This is called a **counter-current system**. The two limbs of the loops of Henle form another counter-current system. The glomerular filtrate flows in the opposite directions in the limbs of loop of Henle. These counter-current systems significantly contribute to concentrating urine in mammalian kidney.

The interstitial fluid of the kidney increases in osmolarity from about 300 to 1200 mosm L^{-1} from the cortex to the inner medulla. Two solutes that contribute to the gradient of osmolarity are NaCl and urea. Loop of Henle maintains the interstitial gradient of NaCl. The filtrate concentration of this salt increases by the loss of water from descending limb, then ascending limb leaks the salt into the interstitial fluid. Additional salt is actively transported out of the thick segment of the ascending limb. The second solute, urea, is added to the interstitial fluid of the medulla by diffusion out of the collecting duct. Urea remaining in the collecting duct is eventually excreted out. Urea reenters the ascending thin segment of the loop of Henle by diffusion. The filtrate makes a total of three trips between the cortex and the medulla – first down, then up through descending and ascending limbs of loop of Henle, respectively, and then down, in the collecting duct. As the filtrate flows down in the collecting tubule past interstitial fluid of increasing osmolarity, more and more water moves out of the tubule by osmosis, thereby concentrating the solutes, including urea that are left behind in the filtrate (Fig. 8.12). Under conditions in which the kidney conserves as much water as possible, urine can reach an osmolarity of about 1200 mosm L^{-1}, considerably hypertonic to blood (about 300 mosm L^{-1}). This ability to excrete nitrogenous wastes with a minimal loss of water is a key adaptive feature that has enabled humans (rather all terrestrial mammals) to lead a successful terrestrial life facing a constant threat of desiccation.

8.6 Regulation of Kidney Function by Feedback Circuits

Two important hormonal controls of the kidney function by negative feedback circuits can be identified :

(i) Control by Antidiuretic Hormone (ADH) : ADH also called vasopression, produced in the hypothalamus of the brain and released into the blood stream from the pituitary gland, enhances fluid retention by making the kidneys reabsorb more water. The release of ADH is triggered when osmoreceptors in the hypothalamus detect an increase in the osmolarity of the blood above a set point of 300 mosm L^{-1}. In this situation, the osmoreceptor cells also promote thirst. Drinking reduces the osmolarity of the blood, which inhibits the secretion of ADH, thereby completing the feedback circuit [Fig. 8.13(a)].

(ii) Control by Juxtaglomerular Apparatus (JGA) : JGA operates a multi-hormonal **Renin-Angiotensin-Aldosterone System** (RAAS). The JGA responds to a decrease in blood pressure or blood volume in the afferent arteriole of the glomerulus and releases an enzyme, **renin**, into the blood stream. In the blood, renin initiates chemical reactions that convert a plasma protein, called **angiotensinogen**, to a peptide, called **angiotensin II**, which works as a hormone. Angiotensin II increases blood pressure by causing arterioles to constrict. It also increases blood volume in two ways : firstly, by signaling the proximal convoluted tubules to reabsorb more NaCl and water, and secondly, by stimulating the adrenal gland to release **aldosterone**, a hormone that induces the distal convoluted tubule to reabsorb more Na^+ and water. This leads to an increase in blood volume and pressure, completing the feedback circuit by supporting the release of renin (Fig. 8.13).

Still another hormone, a peptide called **Atrial Natriuretic Factor** (ANF), opposes the regulation by RAAS. The walls of the atria of the heart release ANF in response to an increase in blood volume and pressure. ANF inhibits the

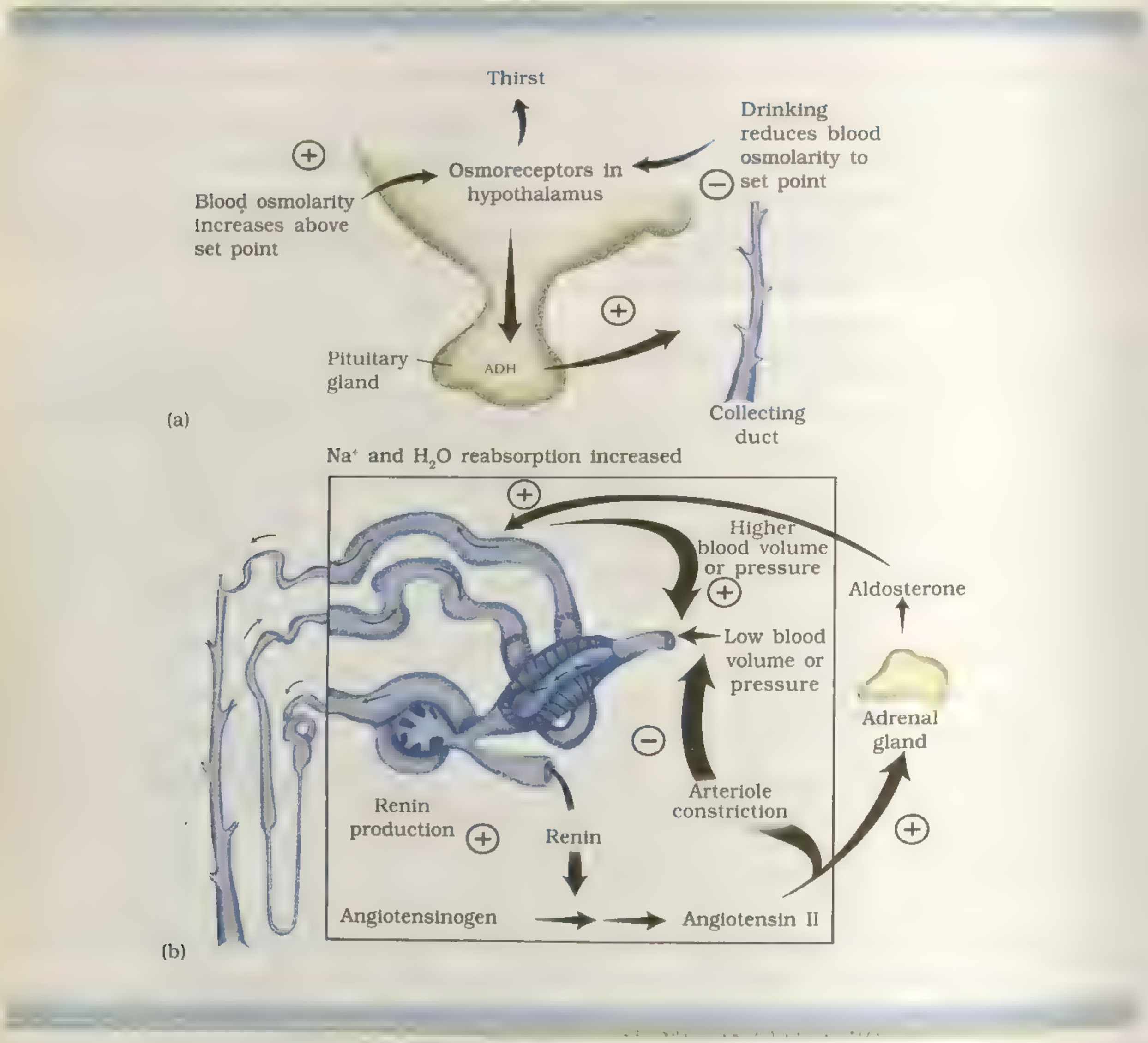


Fig. 8.13 Regulation of renal function by feedback circuits : (a) control by ADH: (b) Control by RAAS

release of renin from the JGA, and thereby, inhibits NaCl reabsorption by the collecting duct and reduces aldosterone release from adrenal gland. Thus, ADH, the RAAS and ANF provide an elaborate system of checks and balances that regulate the kidney functioning, to control body fluid osmolarity, salt concentration, blood pressure and blood volume.

8.7 Micturition and Constituents of Urine

Micturition is the act of voiding the urine. The release of urine is accomplished by the simultaneous contraction of the smooth muscle of the urinary bladder wall and the relaxation of the skeletal muscle of the sphincter around the opening of the bladder. As the bladder wall is stretched by gradual filling of the bladder, stretch receptors in the wall of the bladder generate nerve impulses that are carried by sensory neurons to the spinal cord and brain, producing the sensation of 'fullness' (around 500 ml). The sphincter can then be relaxed by inhibition of motor impulses, allowing the smooth muscle of the bladder wall to contract under autonomic control and empty the contents.

Urine is a pale-yellow coloured, slightly acidic (average pH 6.0; range 4.5-8.2) watery fluid (specific gravity 1.015-1.025) with a characteristic smell. Human adults produce around 1.5 L of urine per day. Composition, colour and volume, however, may change with the nature of dietary intake.

Abnormal urine : Various metabolic errors of kidney malfunctioning are reflected in the changes of the composition of urine. Occurrence of ketone bodies, glucose, albumin, blood cells, excess pigments, pus cells, calculi or casts (kidney stones) are some of the major abnormal constituents of urine. Notable abnormal conditions are as follows :

Proteinuria – excess protein level in urine.

Albuminuria – presence of albumin in urine; usually occurs in *nephritis* (inflammation of glomeruli), when the size of the filtering slits enlarges.

Glycosuria – Presence of glucose in urine, as in the case of *Diabetes mellitus*.

Ketonuria – Presence of abnormally high ketone bodies in urine.

Hematuria – Presence of blood or blood cells in urine.

Hemoglobinuria – Presence of hemoglobin in urine.

Uremia – Presence of excess urea in urine.

8.8 Hemodialysis and Kidney Transplantation

The blood urea level rises abnormally (*uremia*) in patients suffering from renal failures. An artificial kidney is used for removing excess urea from the blood of the patient by a process called **hemodialysis**. Blood is taken out from an artery of the patient, cooled to 0°C, mixed with an anticoagulant, such as heparin, and then pumped into the apparatus called the artificial kidney. In this apparatus, blood flows through channels or tubes bounded by cellophane membrane. The membrane is impermeable to macromolecules, such as plasma proteins, but permeable to small solutes, such as urea, uric acid, creatinine and mineral ions. The membrane separates the blood flowing inside the channels or tubes from a dialysing fluid flowing outside the membrane. The dialysing fluid contains some small solutes and mineral ions, but does not contain nitrogenous waste products, such as urea, uric acid and creatinine. So, these wastes diffuse from the blood to the dialysing fluid across the cellophane membrane, following the concentration gradient. Thus, the blood is considerably cleared of nitrogenous waste products without losing plasma proteins. Such a process of separating small solutes from macromolecular colloids with the help of a selectively permeable membrane is called **dialysis**. The blood coming out of the artificial kidney is warmed to body temperature, mixed with an antiheparin to restore its normal coagulability, and returned to a vein of the patient. Hemodialysis saves and prolongs the life of many uremic patients.

If the kidney failure cannot be otherwise treated, by drug or dialysis, the patients are advised for **kidney transplantation**. A donated kidney may come from an anonymous donor who has recently died, or from a living person, usually a relative. The kidney of donor must be a good match for recipient. The more the new tissue from the donor is like the recipient's tissue, the less likely the immune system of the recipient is to reject it. Immune system protects from disease by attacking anything that is not recognised as a normal part of the body. So, the immune system of the recipient will attack a kidney that appears too "foreign". Special drugs can help suppress the immune system of the recipient so it does not reject a transplanted kidney.

8.9 Role of Lungs in Excretion

Human lungs eliminate around 18 L of CO_2 per hour and about 400 ml of water per day in normal resting condition. Water loss via the lungs is small in hot humid climate and large in cold dry climates. The rate of ventilation and ventilation pattern (i.e., breathing through mouth or nose) also affect the water loss through the lungs. Different volatile materials are also readily eliminated through the lungs.

8.10 Role of Skin in Excretion

Human skin possesses glands for secreting two fluids on its surface, *viz., sweat* from sweat glands, and *sebum* from sebaceous glands. Sweat is an aquous fluid (around 99.5% water) containing NaCl, lactic acid, urea, amino acids and glucose. The volume of sweat varies from negligible to 14 L a day, rising with activity and temperature. However, principal function of sweat is the evaporative cooling of the body surface. Sebum is a waxy protective secretion to keep the skin oily and this secretion eliminates some lipids, such as waxes, sterols, other hydrocarbons and fatty acids. Integument in many aquatic animals is excreting ammonia into the surrounding medium by diffusion.

8.11 Role of Liver in Excretion

Liver is the main site for elimination of cholesterol, bile pigments (bilirubin and biliverdin), inactivated products of steroid hormones, some vitamins and many drugs. Liver secretes these substances in bile. Bile, in turn, carries these materials to the intestine, which are ultimately eliminated with the faeces.

SUMMARY

The specialised transport epithelia of animals are engaged in osmoregulation (the regulation of solute movement and hence water movement, which follows solutes by osmosis) and excretion (elimination of nitrogen containing waste products of metabolism). Some animals show an excellent ability to tolerate a wide range of cellular osmotic environments (osmoconformers), while there are animals that maintain an internal osmolarity (osmoregulators).

The nature of the nitrogen containing wastes and their excretion varies among animals depending on water availability. Animals generally excrete most excess nitrogen as *ammonia*, *urea* or *uric acid*.

Simple tubular systems like protonephridia, metanephridia, malpighian tubules, green glands, and the complex tubular systems like the vertebrate kidneys, help in elimination of nitrogen containing wastes.

Human urinary system, i.e., the system of excretion through kidneys, consists of two kidneys and their blood supplies, a pair of ureters (that carries urine from the kidneys to the bladder), a urinary bladder (that temporarily stores urine) and a urethra (that carries urine from the bladder to the exterior).

Human kidney filters the equivalent of the blood volume every 4-5 minutes, i.e., around 1300 ml of blood flows per minute. Two important intrinsic mechanisms, myogenic mechanism and juxtaglomerular apparatus, provide autoregulation of glomerular filtration rate (GFR). The functional unit of kidney is nephron. Nephron tubule is closed at its beginning but open at its distal end. At the closed end, the nephron is expanded and curved inwardly to form the double-walled cup-shaped Bowman's capsule. Within the Bowman's capsule, there is a tuft of capillaries called glomerulus. Glomerulus and its surrounding Bowman's capsule together form the specialised structure – malpighian corpuscle. Non-selective ultrafiltration takes place in malpighian capsule which is responsible for the first step of urine formation. Glomerular

filtrate, almost identical to plasma in overall osmolarity and concentrations of small solute, gradually changes its composition as it passes down the renal tubule and ultimately becomes urine. Proximal Convoluted Tubule plays an important role in homeostasis by its controlled secretion and reabsorption of several substances. Descending limb of the loop of Henle is permeable to water but not to salt. Osmotic loss of water from the filtrate helps to concentrate NaCl in the filtrate. The salt that was concentrated in the filtrate within the descending limb, passively diffuses out of the ascending limb of the loop of Henle contributing to a high interstitial osmolarity in the inner medulla of kidney. Distal convoluted tubule helps regulate blood pH by reabsorption of HCO_3, an important buffer. The distal tubule also functions in K^+ and Na^+ homeostasis. Collecting tubule is permeable to water but not to salt. The filtrate becomes more and more concentrated here, as water is lost to the interstitial fluid. Under conditions in which the kidney conserves as much water as possible, urine can reach an osmolarity of about 1200 mosm L^{-1}, considerably hypertonic to blood (about 300 mosm L^{-1}). This ability to excrete nitrogenous wastes with a minimal loss of water, is a key adaptive feature that has enabled humans (rather all terrestrial mammals) to lead a successful terrestrial life facing a constant threat of desiccation. Skin, lungs and liver serve as the secondary sites of excretion.

EXERCISES

1. Indicate whether the following statements are true or false :
   (a) Micturition is carried out by a reflex.
   (b) ADH helps in water elimination, making the urine hypotonic.
   (c) Protein-free fluid is filtered from blood plasma into the Bowman's capsule.
   (d) Henle's loop plays an important role in concentrating the urine.
   (e) Glucose is actively reabsorbed in the proximal convoluted tubule.

2. Match the items of column I with those of column II :

Column I	Column II
(i) Ammonotelism	(a) Birds
(ii) Bowman's capsule	(b) Hypertonic urine
(iii) Micturition	(c) Counter-current system
(iv) Uricotelism	(d) Bony fish
(v) Vasa recta	(e) Urinary bladder
(vi) Sebum	(f) Glucose
(vii) ADH	(g) Glomerular filtration
(viii) Tubular reabsorption	(h) Skin

3. Fill in the blanks with appropriate words :
   (a) During micturition, the urinary bladder ________ and the urethral sphincters ________.
   (b) Flame cells and malpighian tubules are found in ________ and ________, respectively.

(c) Blood enters the glomerulus through ________ arteriole and leaves via the ________ arteriole.
(d) Two counter-current systems are formed in the kidney by the __________ and the ____________.
(e) Sweat serves to eliminate mainly __________ and __________.

4. Explain the following :
   (a) Skin functions as an accessory excretory organ.
   (b) Mammals can eliminate hypotonic and hypertonic urine according to body needs.
   (c) Micturition is a reflex process, but is under some voluntary control.
   (d) Mammals are ureotelic, but birds are uricotelic.
5. Compare and contrast the osmoregulatory problems and adaptations of a marine bony fish with a freshwater bony fish.
6. State the importance of counter-current systems in renal functioning.
7. Describe the gross anatomical features of human kidney with suitable diagram.
8. Describe the functional anatomy of human nephron.
9. Briefly state the mechanism of urine formation in human kidney.
10. State the position and function of juxtaglomerular apparatus.
11. Describe the hormonal feedback circuits in controlling renal functions.
12. State the normal and abnormal constituents of human urine.
13. Write a short account on hemodialysis.
14. State the roles of skin and lungs in excretion.

Chapter 9

Movement and Locomotion in Animals

Movement is the fundamental requirement of organisms. You know that at cellular level, the cytoplasm exhibits streaming movement. At the organismic level, the plants move their parts by phototropism and geotropism. In animals, the ingested food gradually moves downward through the alimentary canal. In humans, the food is swallowed and then passed downward through peristalsis. You can recall that the heart pumps blood, which circulates throughout the body for transporting nutrients and respiratory gases, hormones and nitrogenous wastes. Also, the animal can change the plane of orientation of their appendages or limbs at will. All of these serve as examples of the life activity called **movement**. A few other examples are the movements of eyelids, external ear (pinna), jaws, tongue, tentacles and cilia. You can notice that in none of the above cases, organisms require to change their places. Nevertheless, animals need to change their places for various purposes. These include running, flying, swimming, jumping, crawling, somersaulting and so on. Change of place is referred to as **locomotion**. In fact, it is vital for the survival of the animals as it enables them to procure food, search shelter, find mates, protect themselves from predators and perform many other life activities.

As such, it is difficult to separate movement from locomotion. In animals, locomotion is intimately related to movement. Any change of place involves movement of cytoplasm, cells or tissues. Movements of appendages or limbs, or any other body parts in relation to body axis, can change the body posture for maintaining equilibrium or steady state of the organism. At the same time, an animal cannot change its place (locomote) without movement of flagella or cilia, appendages or limbs. Similarly, movements of cilia, tentacles, limbs, tongue, jaws are commonly observed during capture of food by the animals. Animals also require to move from one place to another for getting food and other things. Clearly, movements are primarily connected with locomotion.

In this chapter, you will be acquainted mainly with the mechanism of locomotion and movement in some animals, including the human. As human locomotion is affected by the interaction and coordination of the muscle, skeletal and nervous systems, you will be introduced with structure and function of human muscle and skeletal systems. The nervous system will be dealt separately in Chapter 10.

9.1 The Basic Types of Movements

Although the uses of movements vary greatly, it involves three basic mechanisms. These are : amoeboid, ciliary and muscular. **Amoeboid movement** is typical of *Amoeba*, which performs the function by producing pseudopodia, involving change in shape of the cell body and streaming movement of cytoplasm. Recent studies also reveal the involvement of cytoskeletal elements, like microfilaments, in amoeboid movement. Amoeboid movement helps in food capture and change of place as well. The same method of movement is also employed by the leucocytes, like phagocytes and macrophages of the human lymphatic system, for engulfment of antigen and migration in the circulatory fluid. **Ciliary movement** is the characteristic way

in which ciliated protozoans, such as *Paramoecium*, move from one place to another in water. *Paramoecium* even uses the cilia of the cytopharynx to drive water and food in their gullet. In fact, cilia present in different animals perform a variety of functions. Cilia set up water currents that pass over the gills of bivalve molluscs (e.g., *Lamellidens*); drive water through the water vascular system of echinoderms (e.g., *Asterias*). The former function is associated with feeding of molluscs, while the latter helps in the locomotion of echinoderms. Ciliary movements of cells lining the upper respiratory tract of humans, help to transport the invading microbes and dust particles. Whereas, the cilia of the Fallopian tube (oviduct) and vasa efferentia of human females and males, transport ova and spermatozoa, respectively. An enlarged version of cilium is known as **flagellum**. Flagella help in the swimming movements of spermatozoa, protozoans like *Euglena* and maintenance of water current in the canal system of sponges. **Muscular movement** is the basic mechanism used in the majority of vertebrates, including humans. This mechanism rests on the use of muscle fibres, which throughout the animal kingdom, has one universal property. This is the ability to exert a force by alternate contraction and relaxation. Most multicellular animals possess muscle fibres for movement of different organs and attaining locomotion.

9.2 Locomotion in Humans

As stated earlier, locomotion in humans depends on the movements of muscle fibres (muscle cells). Muscles cause movements of limbs and internal organs and, thus, coordinate locomotion in humans. Such muscular movement is based on the contractile capacity of the muscle fibres. Some muscles remain associated with skeleton, while many others form walls of many visceral organs. Therefore, it is imperative to learn about the muscles and skeletons before attempting to understand the mechanism of locomotion in humans.

Types of Muscles

You may recall that muscles are made up of contractile fibres which, in turn, are formed of myofibrils. In humans, muscles constitute nearly 40-50 per cent of the total body weight. Muscles are characterised by properties like excitability, contractibility, extensibility and elasticity. In humans, muscles are broadly classified into three categories :

(i) Skeletal muscles : These are attached to the bones by tendons and help in the movement of the parts of skeleton. As these muscles are under control of conscious mind and can be moved at will, these are also termed **voluntary muscles**. These are innervated by voluntary nervous system. Under the light microscope, these skeletal muscles exhibit transverse stripes, and hence, these are designated as **striated muscles**. Skeletal muscles are responsible for movements to facilitate locomotion.

(ii) Cardiac muscles : These muscles are also striated and occur exclusively in the heart. These are not under voluntary control, hence, these are involuntary. These are innervated by autonomic nervous system.

(iii) Smooth muscles : These are the involuntary and non-striated muscles and are innervated by autonomic nervous system. These are found inside the wall of the hollow internal organs, like alimentary canal, reproductive tract, blood vessels, and so on. Smooth muscles help in the movement of materials through the tubular organs.

Structure of Skeletal Muscle

Skeletal muscles remain attached at the firm and non-movable part and the freely movable part of the bones. The tendons by which they are attached to the bones, are made up of connective tissue comprised of collagen. Skeletal muscle consists of numerous physiological units, called **fibre** or **muscle cells**. Bundles of muscle fibres are grouped as **fascicules**, which are held together and enclosed by collagen fibres and by connective tissue. The bundle of fasciculi is surrounded by a tough external layer called **fascia**, lying below the skin. Each muscle fibre is an elongated slender cell. It is syncytial, i.e., multinucleate. Its membrane is called **sarcolemma** and its cytoplasm is called **sarcoplasm**. The mitochondria of the cell are

called **sarcosomes** and the endoplasmic reticulum is designated as **sarcoplasmic reticulum**. Each fibre contains many thin and rod-like **myofibrils**, which bear characteristic cross-striations (Fig. 9.1).

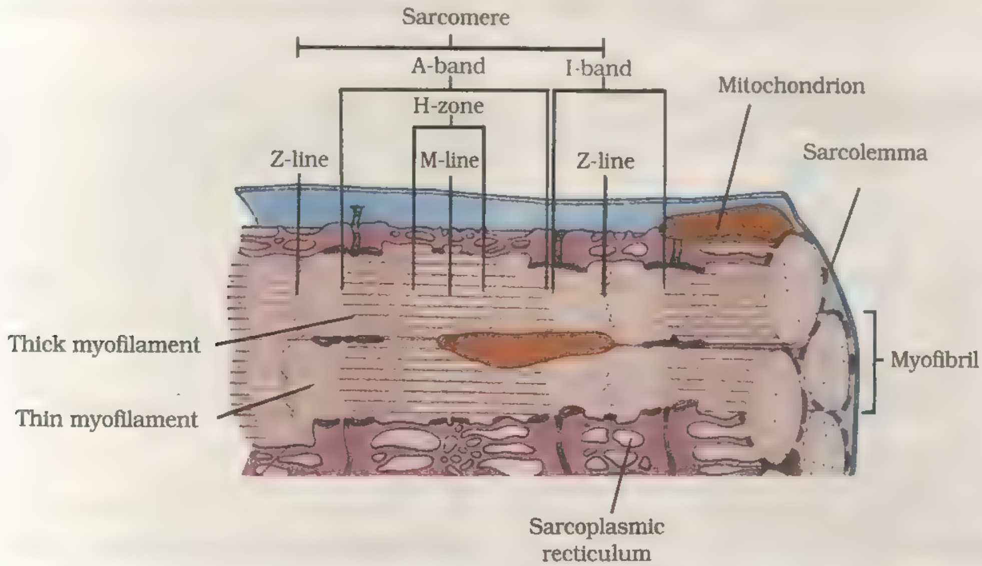


Fig. 9.1 *Myofibrils of a muscle fibre*

The myofibrils are arranged in a number of sections, called **sarcomeres**, joined end to end all along the length of a muscle fibre. Electron microscope reveals that the sarcomeres are delineated by a very thin and comparatively dense Z-line. A dark anisotropic band (A-band) is present in the centre of the sarcomere. Adjacent to this lies a light isotropic band (I-band). Alternate arrangement of dark and light bands gives the striated appearance to a skeletal muscle. At the centre of the A-band, a comparatively less dark zone called H-zone is present. In the centre of H-zone, M-line is present, formed by threads that connects the myofilaments. The Z-line is located at the centre of the I-band.

The sarcoplasm contains many thick and thin filaments. In each sarcomere, the thin filaments are present at the two ends, whereas the thick filaments are located centrally. The two adjacent sarcomeres have almost continuous thin filament having the limiting boundary of Z-line. The thick and thin filaments are alternately arranged and they form overlaps. The H-zone contains only thick filaments, while the I-band contains only thin filaments. The remainder of A-band has both thick and thin filaments.

The thin filaments consist of actins and the thick filaments of myosin (Fig. 9.2). Both **actin** and **myosin** are contractile proteins. Actin has low molecular weight filamentous protein. It occurs in two forms, the monomeric G-actin and the polymeric F-actin. The thin filaments also contain the contractile protein, called **tropomyosin**. It is a rod-shaped fibrous protein; the rods link end to end to form two helical strands, which are wrapped around the F-actin.

Another small globular protein molecule, called **troponin**, masks the active sites on the F-actin (Fig. 9.2). Each myosin molecule has two components, a tail and a head. The tail is

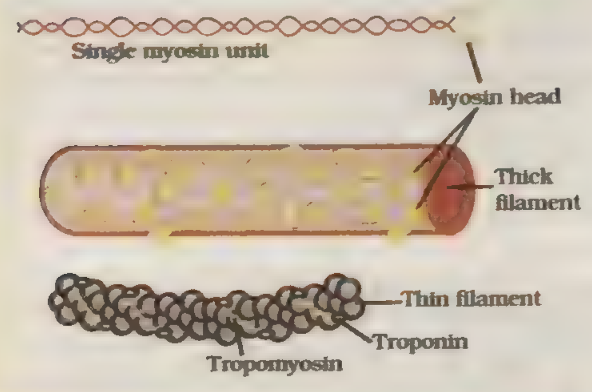


Fig. 9.2 Components of thin and thick filaments

formed of light meromyosin (L-MM), while the head is formed of heavy meromyosin (H-MM). Myosin head has contractile property as well as ATPase like action; it can form a cross-bridge with the active site present on the actin.

The Mechanism of Muscle Contraction

According to **sliding filament theory** of muscle contraction, during contraction, the

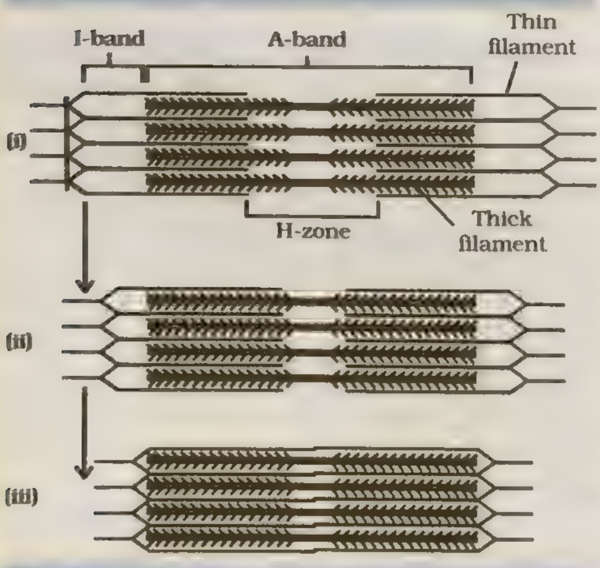


Fig. 9.3 Events during muscle contraction

actin and myosin filaments slide past each other to reduce the length of the sarcomeres (Fig. 9.3). The actin filaments move inwards towards the centre of the sarcomere, i.e., deeper into the A-bands. The heads of the myosin filaments operate as 'hooks'; attaching to the F-actin they form cross-bridges, then change their relative configuration and pull the actin filaments further deep into the A-band. As a result, the Z-lines limiting the sarcomeres, are drawn closer together (Fig. 9.3 ii, iii). But the length of the A-band remains unchanged. Actually, the I-bands reduce in length. However, the net result is the shortening of the sarcomere. The actin filaments slide out from the A-band, resulting in the lengthening of the sarcomere.

Muscle fibres are excitable. However, they differ in their threshold value for stimuli, length, diameter, reaction time, and period of relaxation. Normally, a nerve impulse arriving at the neuromuscular junction initiates contractile response. The impulse spreads rapidly due to depolarisation of the surface of the sarcomeres. A neurotransmitter released at the neuromuscular junction, enters into the sarcomere through its membrane channel. The opening of the channel also results in the inflow of Na^+ inside the sarcomere and generates an action potential in the muscle fibre. This action potential travels all along the length of the muscle fibre. The sarcoplasmic reticulum releases the stored Ca^{++}, which binds with the specific sites present on the troponin component of the thin filament. As a result, conformational change occurs in the troponin molecule and the active sites present on the F-actin molecules are exposed. These sites are specific to the myosin head, which exhibits Mg^{++} dependent ATPase activity. During relaxation of the muscle, the Ca^{++} is pumped back into the sarcoplasmic reticulum. As a result, the troponin component becomes free to mask the active sites for the myosin head. The cross-bridge breaks and the thin filament occupies its normal position. The muscle relaxes.

Red and White Muscles

The skeletal muscles are of two types, red and white muscles. The basis of such a classification is the presence of a red pigment,

called **myoglobin**, in it . The red muscles contain very high amount of myoglobin, whereas the white muscles contain very low amount. Myoglobin can store oxygen, which is utilised by the mitochondria for the synthesis of ATP as and when required. The differences between the red and white muscles are given in Table 9.1.

Table 9.1 : Comparison between Red and White Muscles

	Red muscle	White muscle
Diameter	Smaller	Bigger
Mitochondria	More in number	Less in number
Blood capillaries	More	Less
Sarcoplasmic reticulum	Less	More

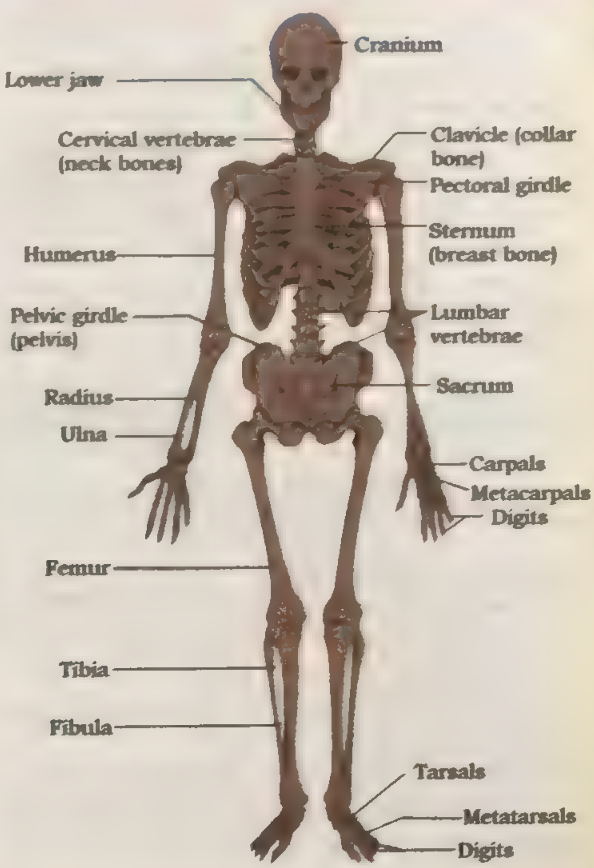


Fig. 9.4 *Human skeleton*

The Skeletal System

The human endoskeleton is made up of bones and cartilage of various types. Bone is a hard connective tissue in which the ground substance is very hard and contains calcium salts. The ground substance has enormous irregular spaces, called **lacunae**, in which the osteocytes are present. Cartilage is a firm and elastic skeletal connective tissue with large number of chondrocytes embedded in the matrix. Bone and cartilage help individuals to sit, walk and run; they also provide protection to many vital organs like brain, eyes and heart. Skeleton serves as the reservoir of many minerals, like calcium and phosphate. The marrow of the long bones is the site for the haemopoiesis, i.e., formation of blood and blood cells. Most importantly, the skeleton plays a vital role in movement and locomotion.

Human skeleton consists of 206 pieces of bones (Fig. 9.4). Few cartilages are also present, which provide support to structures like ear, nose and larynx. Bones and cartilages are connective tissues. The bones are associated with each other with the help of either joints or sutures. The skeletal system is categorised into **axial skeleton** and **appendicular skeleton**.

Axial skeleton consists of skull, vertebral column, ribs and sternum, that is, the skeletal elements which are present along the longitudinal axis of the body. There are 80 bones in this.

The Skull consists of 29 bones, separated by sutures having the following parts (Fig. 9.5) :

(a) *Cranial bones* : These are 8 flattened bones, which are tightly interlocked, forming a box, called **cranium**, in which brain remains protected. The upper jaw is fused with the cranium, whereas the lower jaw remains connected with the cranium by muscles.

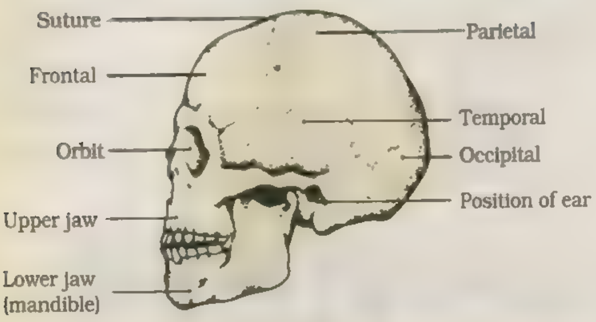


Fig. 9.5 *Human skull*

(b) *Facial bones* : These are 14 in number and form the front part of the skull along with skeleton of nose, hard palate and lower jaw.

(c) *Hyoid bone* : It is a bone placed at the floor of the buccal cavity.

(d) *Bones of middle ear* : These are three in number, namely malleus, incus and stapes.

At the posterior end of the cranium are two smooth and rounded protuberances, the **occipital condyles**, that articulate with the first vertebra (atlas).

Vertebral column : It is formed of a series of bones called **vertebrae** (Fig. 9.6). In humans, 26 vertebrae are present serially along the length of the trunk starting behind the occipital bone of the skull. The vertebral column is the main axis of the body, which articulates with skull, pectoral girdle, pelvic girdle and the ribs. Each vertebra is centrally hollow. This makes the vertebral column a hollow tube through which the spinal cord coming out of the foramen magnum of the cranium passes, and thus, remains protected.

The vertebrae are named on the basis of the region of the body where they are located. In the neck region, they are called **cervical vertebrae**, while in the thoracic and abdominal regions they are named **thoracic** and **lumbar vertebrae**, respectively. Cervical vertebrae are

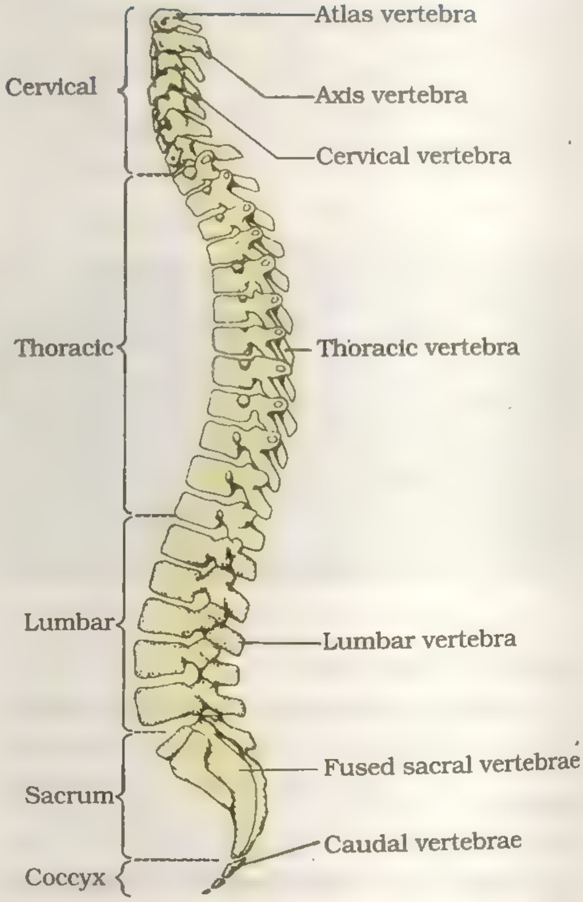


Fig. 9.6 *Human vertebral column*

7 in number, thoracic vertebrae are 12 and lumbar are 5 in number. In the lowermost region of the vertebral column, two triangular fused bones, called **sacral vertebrae** and **coccyx**, are present (Fig. 9.6).

Sternum : The thorax is supported by sternum on the ventral side and the thoracic vertebrae on dorsal side. Sternum (breast bone) is a flat and narrow bone of approximately 15 cm in length situated along the midline of the thorax (Fig. 9.7).

Ribs : The ribs have two facets, which articulate ventrally to the sternum and dorsally to the thoracic vertebrae.

Fig. 9.7 *Sternum*

There are twelve pairs of ribs, which support the sides of the thoracic cavity. Each rib remains attached to the respective thoracic vertebra. The first seven ribs, called true ribs gradually increase in size and are attached directly with the sternum with the help of a hyaline cartilage. Out of the rest of five ribs, the eighth, ninth and tenth remain attached to each other, and also with the seventh rib with the help of cartilage. These are called **vertebrochondral ribs**. The last two (eleventh and twelfth) ribs remain free anteriorly, and hence, called **floating ribs**. The thoracic vertebrae, ribs and sternum, together form the rib cage (Fig. 9.8).

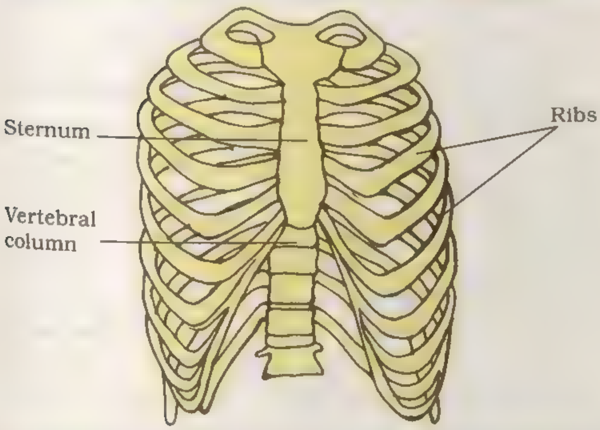


Fig. 9.8 *Ribs and rib cage*

Appendicular skeleton : It consists of fore- and hind-limbs, and pectoral and pelvic girdles. There are 126 bones present in the human appendicular skeleton.

Limb bones : These are divided into arm bones and leg bones. Each arm has 30 bones, which constitute **humerus** (upper arm), **ulna** and **radius** (lower arm), **carpals** (wrist), **metacarpals** (palm), and **phalanges** (digits). Ulna is situated towards the little finger side, whereas radius towards the thumb side. The thumb has two bones, whereas the other fingers have three bones, i.e., proximal, middle and distal. Figure 9.9 shows the bones of fore limb and pectoral girdle. Each leg has 30 bones. Thigh (upper part of the leg) has the support

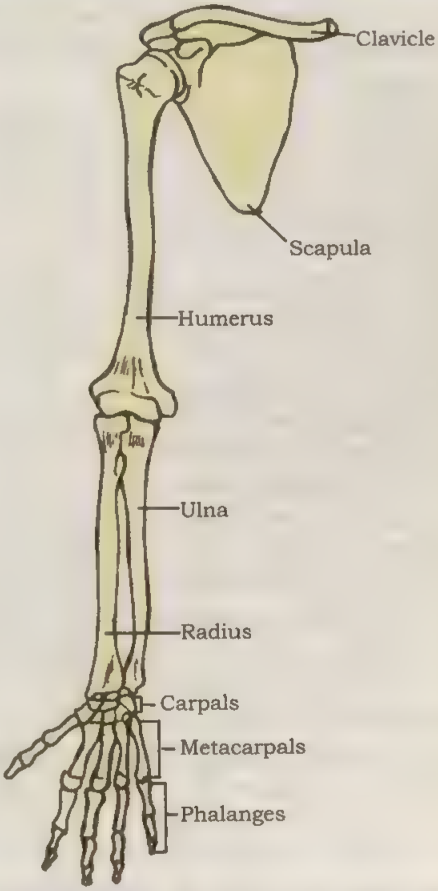


Fig. 9.9 *Bones of forelimb and pectoral girdle*

of the longest and heaviest bone of the body, i.e., **femur**. **Tibia** and **fibula bones** together support the shank of the leg; tibia is larger than fibula and bears the major body weight. Proximally, tibia articulates with femur. At the distal end, both tibia and fibula together articulate with the **talus bone** of the tarsals. **Tarsals** of each leg consist of seven bones forming the ankle. Five **metatarsals** distally articulate with the phalanges or finger bones of the leg. Like the hand, the big toe has two large phalanges and the rest of the toes are made up of three phalanges. Figure 9.10 shows the bones of hind limbs and pelvic girdle. Kneecap is formed by a triangular bone, **patella**, which interiorly articulates with the condyle of femur.

Girdle bones : These provide a connection between the axial skeleton and limbs. The two girdles are named as **pectoral** and **pelvic girdles,** respectively. Each girdle is formed of two halves.

Each half of pectoral girdle consists of a **clavicle** and a **scapula** (Fig. 9.9). Clavicle is a long bone with two curves. Scapula forms the shoulder blade, which is present on the backside of the thorax above the second to seventh rib. There is a ridge, called **spine** present diagonally across the triangular body of the scapula with a process called **acromion**. It articulates with the clavicle. Below this process, a depression is present, called **glenoid cavity** which articulates with the head of the humerus.

Each half of pelvic girdle consists of **ilium, ischium** and **pubis** (Fig. 9.10). Ilium is largest and superior. Pubis and ischium are inferior and are situated anteriorly and posteriorly, respectively. At the point of fusion of the three bones, a cavity is present, called **acetabulum**, that articulates with head of the femur. The pelvic girdle has two coxal bones forming the hipbone (Fig. 9.10). Anteriorly, the coxal bones are jointed at the line of fusion where the two halves of the pelvic girdle meet (pubic symphysis), while posteriorly, they are united with the sacral bones. The sacrum and coccyx together form the basin-shaped pelvis.

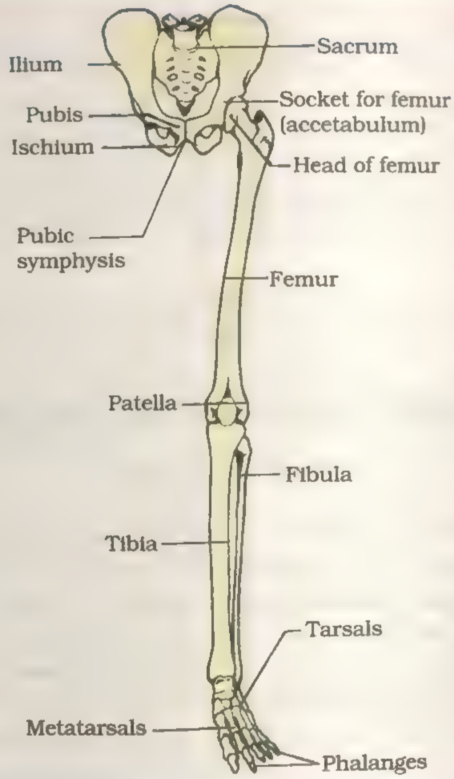


Fig. 9.10 *Bones of the hind limb and pelvic girdle*

Joints : Joints are the place of articulation between two or more bones, or between a bone and a cartilage. Due to the presence of a number of joints, the movement of the different body parts and the whole body is possible. There are few joints along which movement is not possible. There are three types of joints :

(a) *Fixed or immovable or fibrous* : There is no space between the bones. The attached bones are very tightly held with the help of white fibrous connective tissue. **Sutures** present between the skull bones and the articulation of the roots of teeth with sockets of maxillae and mandible, are two examples of such a joint [Fig. 9.11(a)]

(b) *Slightly movable or cartilaginous* : It is an articulation between the bones that allows

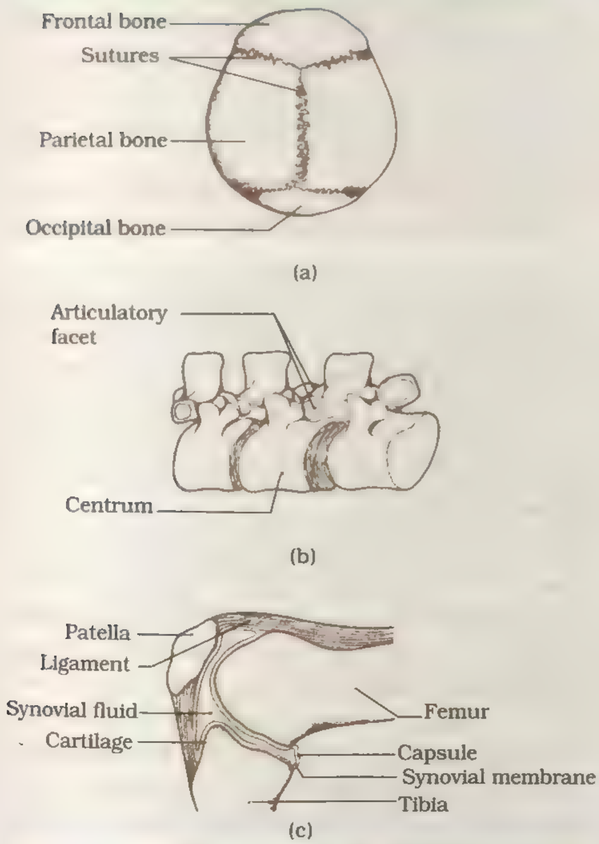


Fig. 9.11 *Three types of joints*

very little movement. In such joints, the opposing surfaces are connected by fibrocartilage. For example, joints between adjacent vertebrae [Fig 9.11(b)].

(c) Movable joints or synovial : It is a joint which allows the movement of articulating bones such that they can move extensively upon each other. In such joints, a space between the bones is present, called **synovial cavity**. This cavity remains filled with a viscous and slippery **synovial fluid** [Fig. 9.11(c)]. Synovial joints can be (i) ball and socket joints, (ii) hinge joints, (iii) pivot joints, (iv) gliding joints, and (v) ellipsoidal joints.

Role of Muscles and Bones in Movement

Movement of an organ occurs due to the pulling of the bones caused by the force generated by contracting muscles. Movement takes place along the joints which act as fulcrum of the lever. In fact, the bones and joints, function as lever, about which you have studied in physics. Functioning of all the three types of levers can be observed in the human skeleton (Fig.9.12). The joint between the first vertebra (atlas) and occipital bone of skull exhibits the example of first class lever, in which joint is the fulcrum, contraction of back muscle is the effort, and facial part of the skull on raised head acts as the resistance. Human body resting on toes is

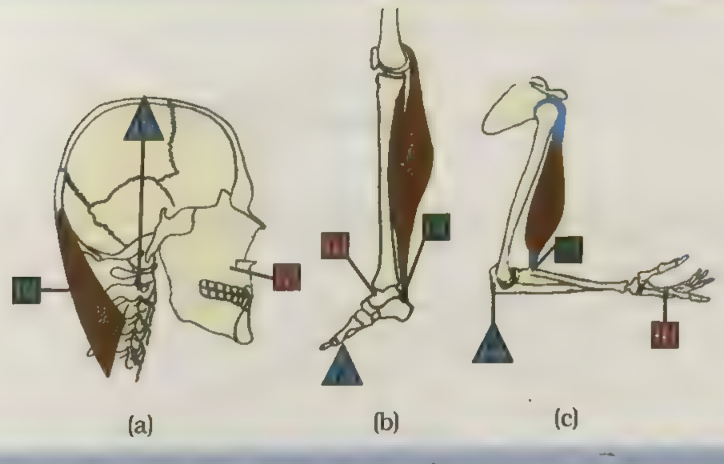


Fig. 9.12 *Role of bones and muscles in movement : (a) Joint between first vertebra and skull on the principle of first type of lever (b) Human body resting on toe as second type of lever (c) Elbow joint of forearm as third type of lever (E=Effort, F=Fulcrum, R=Resistance)*

the example of second class lever, as the toe forms the fulcrum and contracting calf muscle provides effort distally. The body functions as resistance exerting in between the fulcrum and effort. The flexing movements of the elbow of forearm are based on the principle of third-class lever. Here, the elbow-joint acts as fulcrum and the distal part of hand provides resistance. The contracting biceps muscles attached near the elbow joint exert the effort in between fulcrum and resistance.

9.3 Disorders of Bones

Arthritis

It is caused by the inflammation of the joints. This is of several types, e.g., **rheumatoid arthritis, osteoarthritis** and **gouty arthritis**.

(i) ***The rheumatoid arthritis*** : It is diagnosed by the presence of rheumatoid factor (a type of immunoglobulin IgM). It is the primary symptom of inflammation of synovial membrane. If it is left untreated, then the membrane thickens and synovial fluid increases, exerting pressure that causes pain. The membrane then starts secreting abnormal granules, called **pannus**, which after accumulating on the surface of the cartilage, cause its erosion. As a result, the fibrous tissues are attached with the bones and become ossified, making the joints immovable. Its treatment concentrates on reduction of pain and inflammation by heat treatment and physiotherapy and, in extreme cases, replacement of the damaged joints.

(ii) ***Osteoarthritis*** : is a degenerative joint disease characterised by the degeneration of the articular cartilage and proliferation of new bones. Usually, afflicted joints are of spine, knees and hands.

(iii) ***Gouty arthritis or gout*** : It is caused either due to excessive formation of uric acid, or inability to excrete it. It gets deposited in joints as monosodium salt.

Osteoporosis

It is an age-dependent systemic disorder characterised by low bone mass, microarchitectural deterioration of the bone, increased fragility and proneness or susceptibility to fracture. The elderly men and women in particular are most susceptible. It may occur in a pregnant woman. In individuals under prolonged treatment of cortisone, the skeleton fails to withstand the stress of the body and bones are easily fractured. Imbalances of hormones like thyrocalcitonin, parathyroid and sex-hormones, deficiencies of calcium and vitamin D, are the major causative factors.

SUMMARY

Movement and locomotion are necessary for all the vital activities among animals. This phenomenon is observed in all the animal forms, ranging from the acellular protozoans to the multicellular and complex animals, like humans.

The three basic types of movements are : amoeboid, ciliary and muscular movements. Among the multicellular organisms, muscles are essentially required for movement and locomotion. In humans, the muscles are of three types – skeletal, smooth and cardiac muscles. Skeletal muscles are made up of myofibrils which consist of sarcomeres (cells). The myofibrils show light and dark bands represented by thin and thick filaments, respectively. The thin filaments are mainly made up of actin proteins and the thick filaments of myosin proteins. The heads of thick filament form cross-bridge with actin during contraction of the muscles.

Human skeleton consists of bones and cartilages. It provides mechanical support to the body and protects the soft vital organs. Skull, vertebral column, ribs and sternum form the axis of the skeleton. Limbs are attached to the axial skeleton with the help of girdles. The bones at joints and muscles act as lever to bring about movement.

Arthritis and osteoporosis are the common diseases related to bones, affecting mainly the elderly persons.

EXERCISES

1. Why are movement and locomotion necessary among the animals ?
2. Elucidate the types of movements found among the animals.
3. What is muscle ? Write the names of different types of muscles.
4. Write true or false :
   (a) Actin is present in thin filament
   (b) H-zone of striated muscle fibre represents both thick and thin filaments.
   (c) Human skeleton has 207 bones.
   (d) There are 11 pairs of ribs in man.
   (e) Sternum is present on ventral side of the body.
5. How does the skeletal muscle contract ?
6. Write the difference between :
   (a) Actin and Myosin
   (b) Red and White muscles
   (c) Movable and Immovable joints
7. Fill in the blanks :
   (a) Troponin is a part of ________________ filament.
   (b) Head of ________________ has ATPase activity.
   (c) Humerus, radius and ____________ bones are found in the forearm.
   (d) Acetabulum is present in the ____________ girdle.
   (e) Ball and socket joint is a ______________ joint.
8. Match Column I with Column II :

Column I	Column II
(i) Smooth muscle	(a) Myoglobin
(ii) Tropomyosin	(b) Third-class lever
(iii) Red muscle	(c) Thin filament
(iv) Skull	(d) Sutures
	(e) Involuntary

9. What is a joint? Write its type with examples.
10. What is the role of girdles in skeleton ?
11. How does calcium affect the process of muscle contraction ?
12. How are thick and thin filaments arranged in a muscle fibre ?
13. What is arthritis ? How is it caused ?
14. Write the names of the factors which are responsible for osteoporosis.
15. How do the joints help in movement ? Explain.

Chapter 10

Nervous Coordination and Integration in Animals

In the preceding chapters, you have studied a number of physiological processes of animals. You can recall that each physiological function requires regulation and control i.e., they cannot run in an uncontrolled or wild manner. Regulation means adjustment of the variables that determine the nature of physiological functions. These variables may be an amount, a concentration, a rate, and so on. Regulation keeps these variables at optimum or desired level. For example, the transport of O_2 and CO_2 should take place at the level as per the requirement of an animal. For any physiological function, therefore, it is imperative that it should be performed in a controlled way. Again, the different physiological functions are not independent events. All functional components need to be controlled and put together so that they operate harmoniously. This ensures integration of all the systems into a smoothly operating organism. In animals, physiological functions are coordinated by both the nervous and endocrine systems.

In this chapter, you will learn about the nervous systems of cockroach and humans. Next, you will be introduced the mechanism involved in the nervous coordination, such as the transmission of nerve impulse, role of a synapse and the nature of reflex action. At the end, you will be acquainted with structure and function of some human sense organs.

10.1 Nervous System

The **nervous system** comprises highly specialised cells (neurons), whose function is to detect and receive innumerable bits of information (stimuli) from the different sensory organs (receptors), and then, integrate all these to determine the mode of response of the living body. This system codes the sensory information in the form of electrical impulses and transmits them to other cells for their response. The nervous system of higher organisms performs three basic functions : **receiving** sensory input from internal and external environment and conducting it to the brain and spinal cord through nerves; **processing** the input information by a central processor, the brain; and **responding** to stimuli transmitting motor commands from the brain to determine the response of the body parts or cells.

Amongst invertebrates sponges lack neurons. In *Hydra*, all neurons are similar and linked to one another, forming a nerve net or plexus between epidermis and gastrodermis. *Planaria* has two nerve cords that converge to form a rudimentary brain. In earthworm, a central nervous system consisting of a single ventral nerve cord and paired segmental ganglia (associative interneurons in the form of ganglia) have evolved. The ganglia give rise to the segmental nerves leading to the tissues.

10.2 Nervous System of Cockroach

The nervous system of cockroach (Fig. 10.1) consists of brain, the ventral nerve cord and ganglia as well as the nerves which arise from the ganglia. The **brain** or **supraoesophageal ganglion** comprises three fused ganglia of the head. The ventral nerve cord is composed of ten ganglia linked by paired connections. One ganglion lies in the head below the oesophagus and is called the **suboesophageal ganglion**.

The paired **circumoesophageal commissures** link the brain to suboesophageal ganglion. Thorax has three **thoracic ganglia**, which are large and conspicuous, while the abdomen holds six **abdominal ganglia**, of which the terminal one is larger than the preceding five.

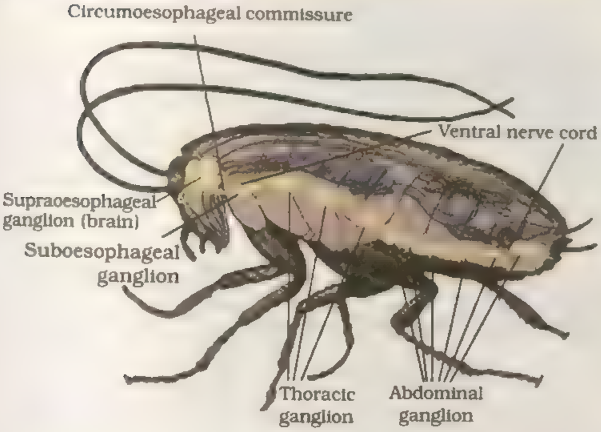


Fig. 10.1 *Nervous system of cockroach*

10.3 Nervous System of Humans

The human nervous system consists of two contrasting functional subsystems, the central nervous system and the peripheral nervous system. Together, **brain** and **spinal cord** make the **central nervous system** (**CNS**). It is the site of information processing within the nervous system. The **peripheral nervous system** (**PNS**) includes all the nerve pathways of the body outside the brain and spinal cord. These pathways are divided into two groups: the **sensory** or **afferent** pathways, which transmit information to the CNS, and the **motor** or **efferent** pathways, which transmit commands from the CNS. The motor pathways, in turn, are partitioned into **somatic (voluntary) nervous system**, which relay commands to skeletal muscles, and **autonomic (involuntary) nervous system** (**ANS**) that stimulates the glands and other muscles of the body. In addition, there is the **neuroendocrine system**, which is a network of endocrine glands whose hormone production is controlled by commands from the CNS. If the neurons are clustered into groups within the CNS, these are called **nuclei**, and if these are in the PNS, these are called **ganglia**. Within the CNS, the bundles of nerve fibres are called **tracts**, whereas in the PNS they are called **nerves**.

A typical nerve has a tough outer covering, the **epineurium**. Inside are the long fibres or axons of individual nerve cells, gathered into bundles called **fascicles**, wrapped in the **perineurium**. Each nerve has its own supply of small blood vessels.

Nerve cells or **neurons** are the functional units of nervous system. These include **multipolar nerve cells**, with many short dendrites and one long axon (e.g., pyramidal cells in cerebral cortex), **bipolar nerve cells**, where the long axon extends on either side of the cell body (e.g., bipolar neurons in the retina of eye), and **pseudounipolar nerve cells**, with the cell body on a side-branch of the main axon (e.g., cells of dorsal root ganglion).

Surrounding neurons are special companion cells, known as **glia** (*Gk : glue*). The glial cells perform many house-keeping functions, provide nutritional support to neurons and consume waste products. They also insulate neuron, separating each from the others.

In the PNS, **Schwann cells**, a type of glial cell, wrap around the axons of neurons, thereby covering the axon with concentric layers of insulating plasma membrane.

The Nerve Impulse

Nerve cells, as well as muscle cells are **excitable cells** because their membranes are **polarised**, having an **electrical potential difference (voltage)** known as **membrane potential**. This is because of differential concentration of ions across the axonal membrane. The axonal

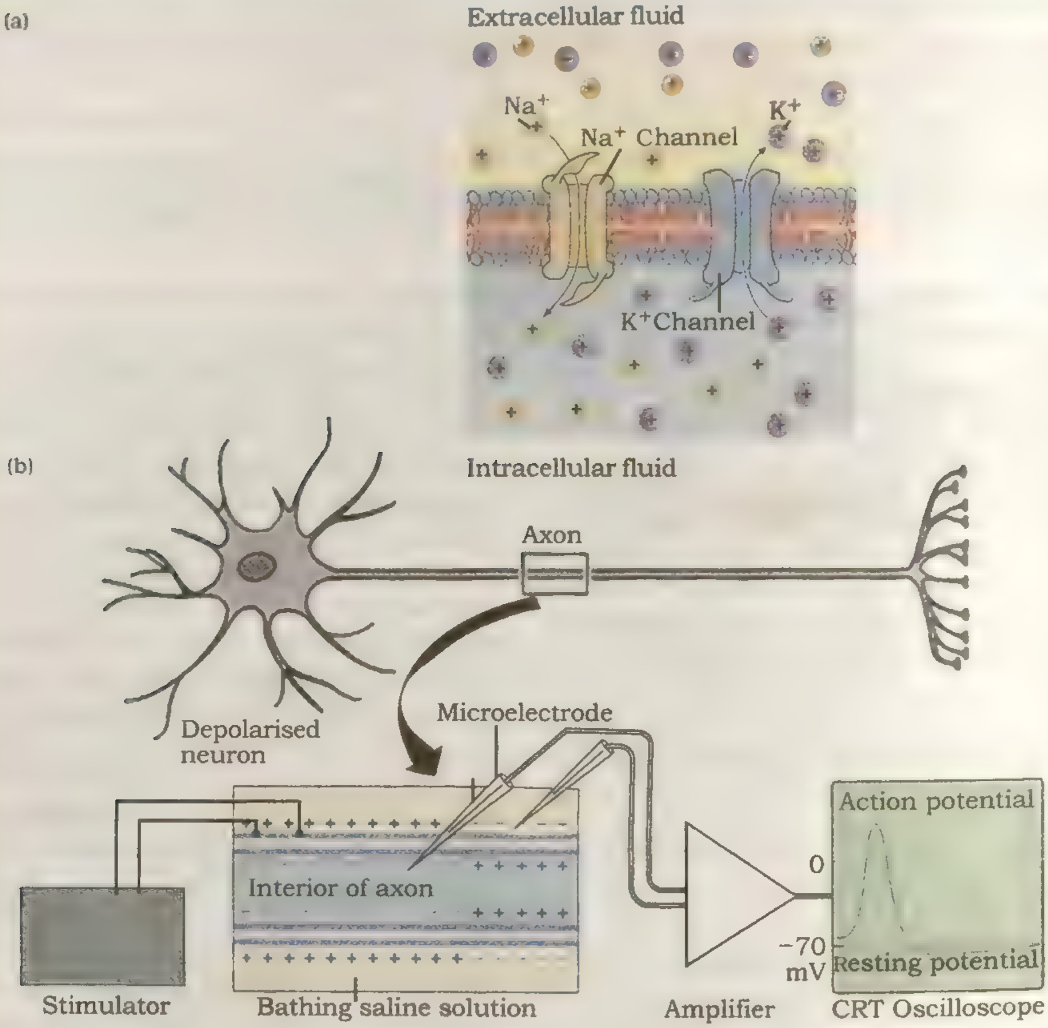


***Fig. 10.2** (a) Axonal membrane showing distribution of ions and ion channels (b) Recording of nerve action potential*

membrane contains a variety of ion channels which are pores formed by proteins (Fig. 10.2). These are selectively permeable, allowing the passage of only one type of ion, say Na^+ or K^+ or Ca^{++} or Cl^-, by remaining either open, or closed. Most ion channels of neurons behave as if they contain a "gate" that opens to allow ions to pass under some conditions, but closes under other conditions. The presence of voltage-gated (regulated) ion channels gives these cells the property of excitability, that is, ability to respond to certain stimuli, such as mechanical pressure, touch, chemicals, light, sound or even just voltage applied. When a neuron is not sending a signal, it is said to be "at rest". The permeability of the

plasma membrane to K^+ ions is greater than its permeability to Na^+ ions in a neuron, or muscle fibre, when these are at rest. The axoplasm inside the axon has a high concentration of K^+ ions and a low concentration of Na^+ ions, in contrast to the fluid outside the axon, which has a low concentration of K^+ ions and a high concentration of Na^+ ions. At rest, K^+ ions can cross through the plasma membrane easily. However, at rest, Cl^- ions and Na^+ ions have more difficulty in crossing. The negatively charged protein molecules inside the neuron cannot cross the plasma membrane because of its semi-permeability. Because of this, the surface of the axon carries a positive charge relative to its interior, and this electrical potential difference across the plasma membrane is called the **resting membrane potential**.

This transmembrane potential can be measured using two electrodes, one inside (intracellular electrode) and one outside (extracellular electrode) in an unstimulated axon. This can be recorded by feeding this input into a dual beam cathode ray oscilloscope (Fig. 10.2), which acts as a sensitive voltmeter. In neurons, the resting membrane potential ranges from –40 to –90 mV (1 milli Volt = 1/1000 Volt). A typical value is –70 mV. The minus sign indicates that the inside is negative relative to the outside.

The electrochemical ionic gradients are maintained by the active transport of ions against the electrochemical gradient by **Na^+-K^+ ion transmembrane pumps**. Each neuron has a million or so ATP-powered Na^+-K^+ exchange pumps built into its membrane to enable it to keep conducting action potentials indefinitely. Each Na^+-K^+ transport pump expels three Na^+ ions for every two K^+ ions imported. Such pumps are said to be **electrogenic**.

Conduction of Nerve Impulse along the Axon

The transmission of a signal by a nerve occurs in four phases :

(i) initiation of the impulse;

(ii) its transmission along a nerve fibre;

(iii) its transfer to a target muscle or nerve ; and

(iv) its effect on the target tissue.

The trigger zone for a particular neuron is the place on the membrane where voltage-gated channels are clustered most densely. When stimulated opening of voltage-gated Na^+ ion channels brings Na^+ ions into the cell, a temporary, very localised, but rapid inflow of Na^+ ions into the cell occurs, wiping out the local electrical potential difference in the immediate vicinity. This is, therefore, called **depolarisation** (Fig. 10.3).

Even though a relatively small number of Na^+ ions cross the membrane before the channel closes again, the interior of the plasma membrane in that area actually develops net positive charge relative to the outside. Depolarisation causes the Na^+ ion channels in the membrane to close so that no more Na^+ ions can enter the cell. After about 0.5 ms, permeability to K^+ ion increases because the build up of positive charge inside the cell opens voltage-gated K^+ channels. Movement of K^+ ions outward down their concentration gradient then re-establishes the charge differences that existed before the stimulus occurred. The exodus of K^+ ions lowers the number of positive ions within the cell, and the potential falls back toward the resting potential. This is referred as **repolarisation**. The whole process of depolarisation and repolarisation is very fast. It takes only about 1 to 5 milliseconds (ms). When the site of stimulation has less charge difference than the membrane surface surrounding it, this potential difference establishes a small, very localised current in the immediate vicinity, which influences the nearby closed Na^+ ion channels to open, permitting Na^+ ions to enter the cell, and depolarising these sites as well. The depolarisation thus spreads, producing a local current, which induces nearby passive Na^+ channels to open, and so, to depolarise the nearby site. In this way, the initial depolarisation passes outward over the membrane and spreads out in all directions from the site of stimulation.

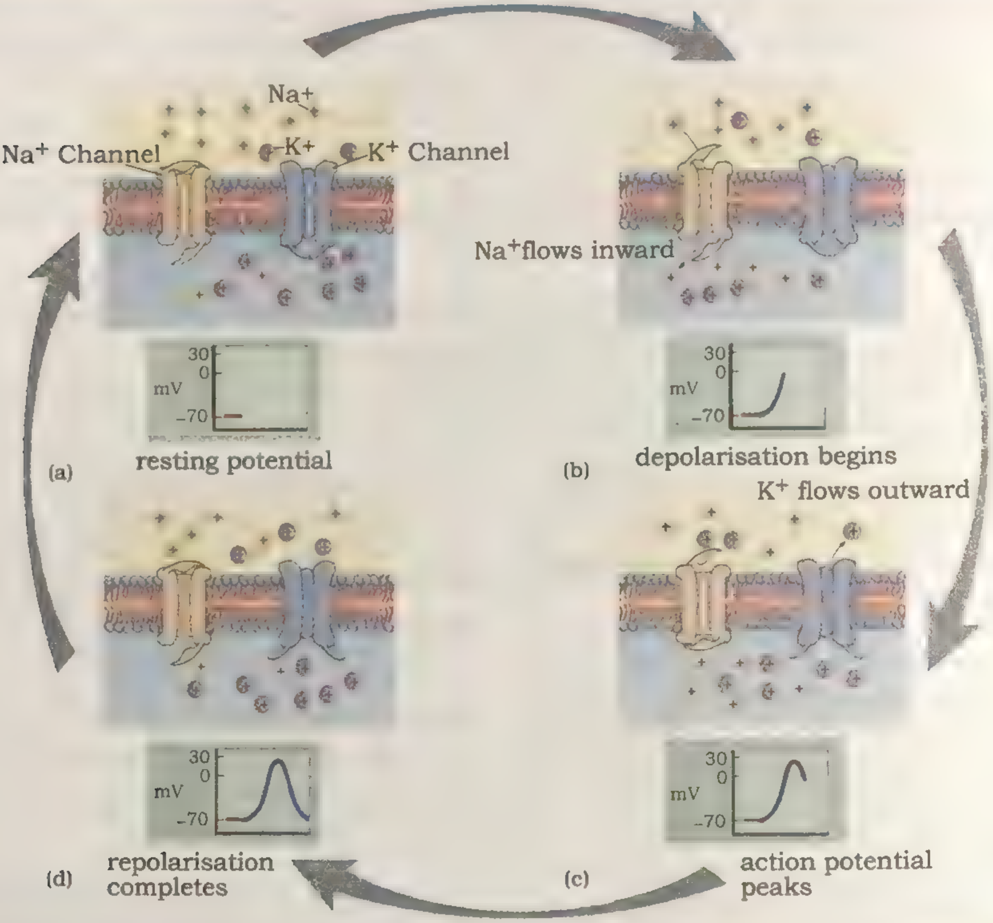


Fig. 10.3 *Stages of axon membrane during resting, depolarisation, action potential and repolarisation, showing changes in membrane potentials and molecular events. (a) Resting state : voltage-gated Na^+ channels are in resting state and voltage-gated K^+ channels are closed. (b) When stimulated above the threshold, depolarisation opens Na^+ channel activation gates, K^+ channels still closed. The open channel lets Na^+ ions flow down their concentration gradient into the axon. The rapid flow continues until a transmembrane potential of about +30 mV is reached. (c) Action potential peaks and repolarisation begins, K^+ channels open allowing K^+ ions flow outward and Na^+ channel gates close and the membrane again becomes impermeable to Na^+ ions (d) Repolarisation completes. K^+ ions exit and Na^+ channels begin to open again.*
** Na^+-K^+ transmembrane pump not shown for simplicity of the figure. It re-establishes the ion gradient.*

Action potentials : Depolarisation is caused by a rapid change in membrane permeability, and a corresponding shift in the balance of ions that is maintained during the resting state. The stimulus required to open enough Na^+ channels to initiate depolarisation is called **threshold stimulus**. For most excitable cells, the threshold is about –55 to –60 mV. This is 10 mV more than the resting potential of –70 mV (Fig. 10.4). If the shift of ions and consequent shift in electrical charges is sufficient enough, It will trigger a wave of transient membrane depolarisation, known as **nerve impulse** or **spike**. **Action potential** is another

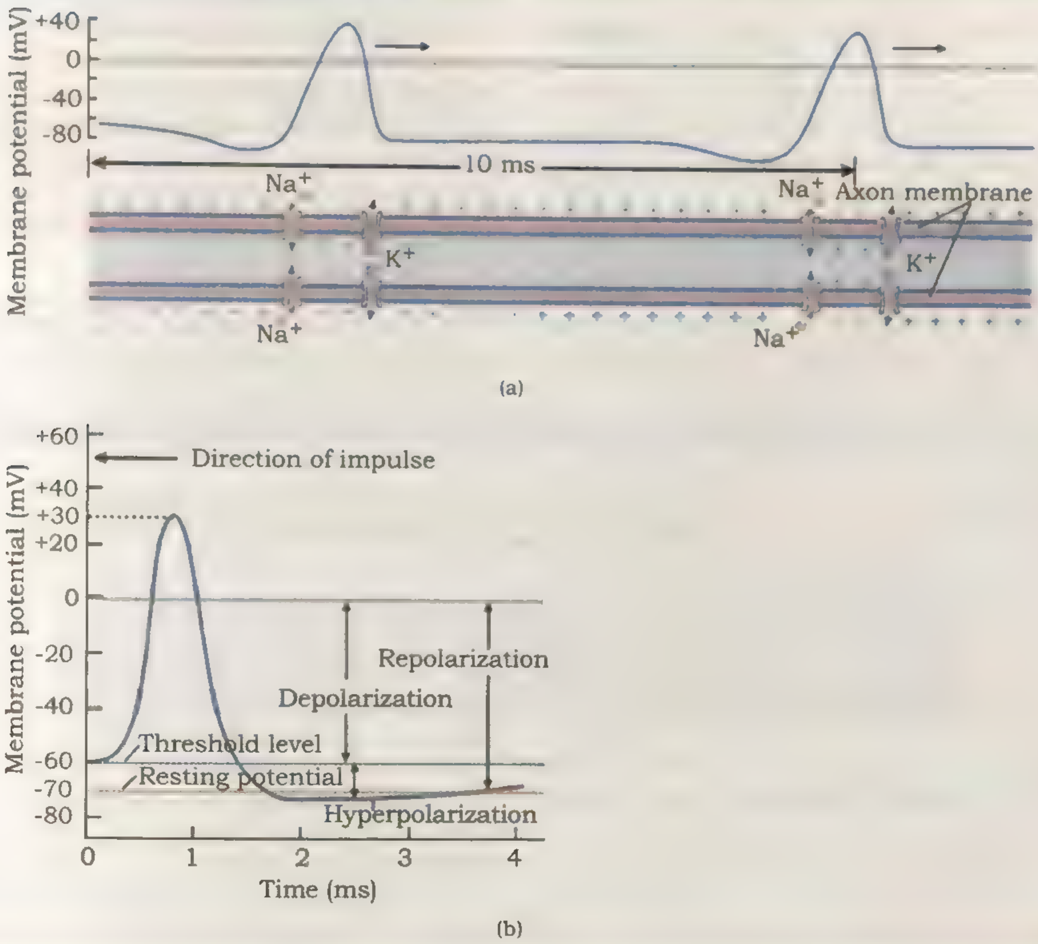


Fig. 10.4 *A typical action potential in an axon. (a) Potential distribution across the axonal membrane (b) Relationships between membrane potentials*

name of nerve impulse, that in contrast with resting potential, propagates along the membrane from one point of neuron to its farthest extensions. This electric relay race whips along the axon, the membrane becoming positive, and then negative again. Therefore, the neuron either does not reach the threshold, or a complete self-propagated wave of action potential is fired. So, action potential is an all or none event.

While the resting potential is determined largely by K^+ ions, the action potential is determined largely by Na^+ ions. The action potential actually goes past –70 mV, because K^+ ion channels stay open a bit too long. Gradually, the ion concentrations go back to resting levels and the cell returns to –70 mV. Because different neurons possess different densities of Na^+ ion channels, different neurons exhibit different action potentials. However, for any one neuron, the action potential is always the same. Any stimulus that opens enough Na^+ ion channels, will propagate an impulse as a wave of depolarisation with a constant amplitude (the strength of the wave). Thus, the stimulus is said to have "fired" the neuron. Every nerve impulse traversing that neuron has the same amplitude, signals differing from one another only in the frequency of these impulses.

Saltatory conduction : Many vertebrate neurons possess axons with sheath at intervals by Schwann cells (e.g., spinal and cranial nerves). These lipid-rich cells envelop the axon, wrapping spirally their plasma membrane around it many times to produce a series of layers, called **myelin sheath**. It acts as a biological electrical insulation, creating a region of high electrical resistance on the axon. Schwann cells are spaced along such an axon one after the other, with **nodes of Ranvier** separating each Schwann cell from the next. These nodes are critical to the propagation of the nerve impulse in these cells. Within the small gap represented by each node, the surface of the axon is exposed to the fluid surrounding the nerve. The ion channels and transport pumps that move ions across the axons, are concentrated in this zone. The direct fluid contact permits ion transport to occur through the channels and an action potential to be generated. The action potential is not propagated by a wave of membrane depolarisation travelling down the axon, since the insulating Schwann cells prevent this. Instead, the action potential jumps as an

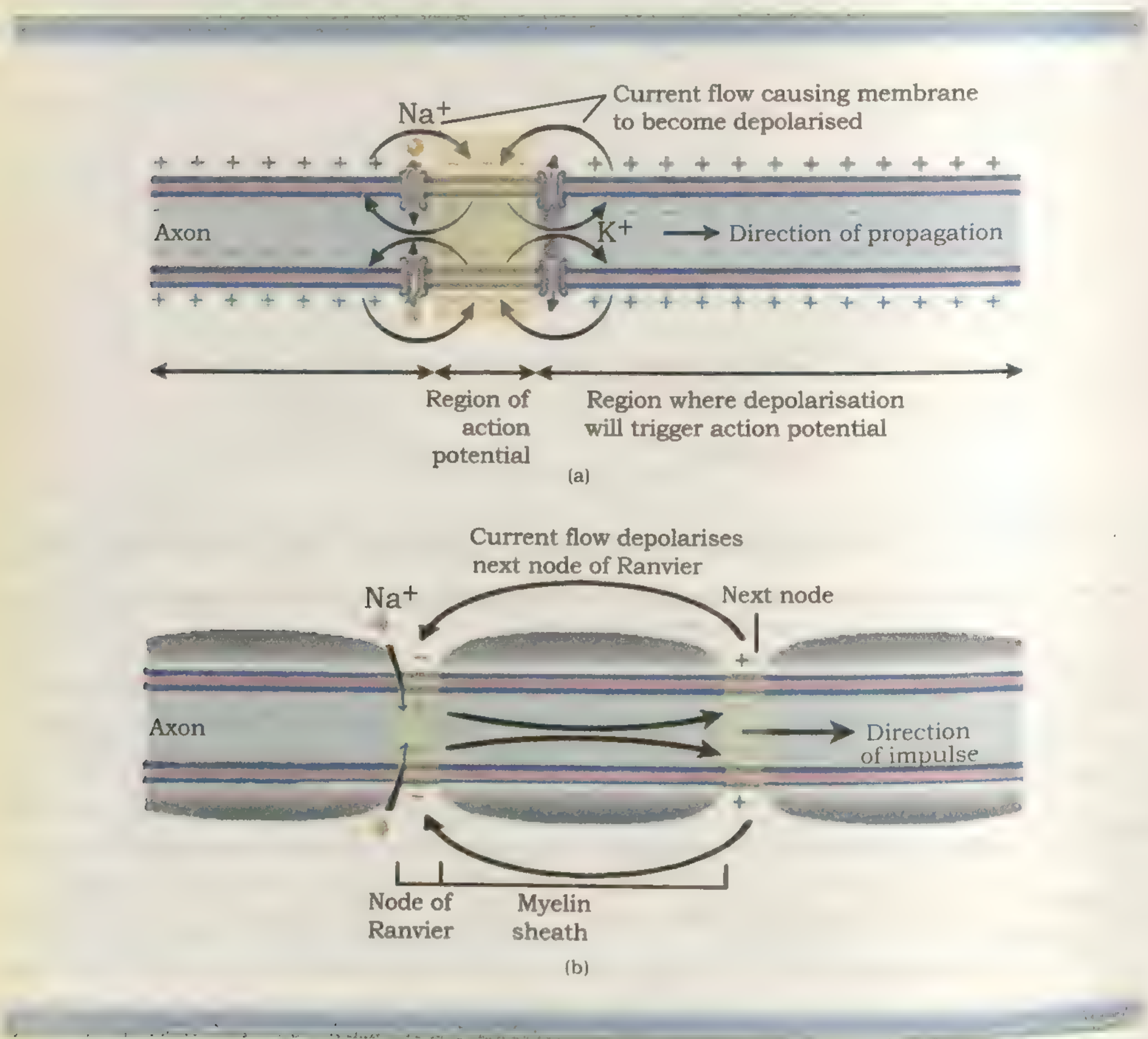


Fig. 10.5 *Difference in the local circuits produced in (a) non-myelinated axon (continuous) (b) myelinated axon (saltatory)*

electrical current from one node to the next. When the current reaches a node, it opens Na^+ ion channels. In doing so, it generates a potential difference large enough to create a current that reaches the next node. The arrival of the current at that node opens its Na^+ channels, creating another current that passes on to the next node, and so on. This very fast form of nerve impulse conduction is known as **saltatory conduction** (*L. saltare* : a jump), since the action potential effectively "jumps" from node to node (Fig. 10.5). An impulse conducted in this fashion moves very rapidly, up to 120 metres per second for large-diameter neurons. Energetically, saltatory conduction is also very economical for the cell, since there is far less membrane depolarisation for the ion pumps to deal with; only the nodes are undergoing depolarisation, instead of the entire nerve surface.

Synapse : Transferring Information from Nerve to Target Cell

An action potential, passing down an axon, eventually reaches the end of the axon that is often branched. It may be associated either with several dendrites, or an axon or a soma of other nerve cells, or with sites on muscle or secretory cells. Nerve signals traverse from neuron to neuron all around the body. These associations are called **synapses** (Fig. 10.6). In a synapse, there is a narrow intercellular gap, 10 to 20 nanometres across, separating the axon tip and the target cell. This gap is called a **synaptic cleft.** The number of synapses is usually very large, providing a large surface area for the transfer of information. For instance, over 1000 synapses may be found on the dendrites and the cell body of a motor neuron in the spinal cord.

There are mainly two types of synapses : (i) electrical, and (ii) chemical, depending upon the nature of transfer of information across the synapse. In **electrical synapses**, which are specialised for rapid signal transmission, the cells are separated by a gap, the synaptic cleft, of only 0.2 nm, so that an action potential arriving at the presynaptic side of cleft, can sufficiently depolarise the postsynaptic membrane to directly trigger its action

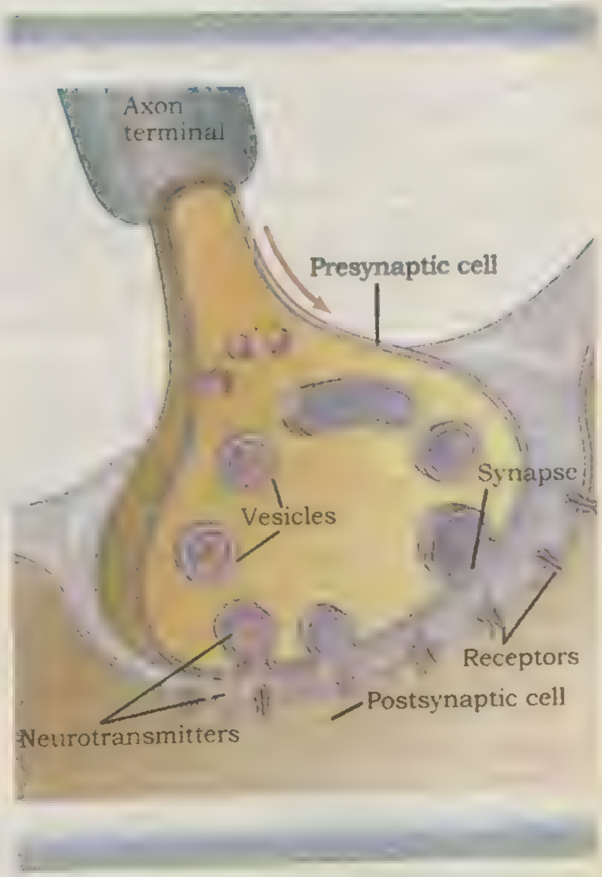


Fig. 10.6 *Neural synapse*

potential. However, more than 20 nm gap of most synapses is too great a distance for such direct electrical coupling. **Chemical synapses**, the commonest type of synapse, consist of a bulbous expansion of a nerve terminal, called **synaptic knob**, lying in close proximity to the membrane of a dendrite. The cytoplasm of the synaptic knob contains numerous tiny, round sacs, called **synaptic vesicles**. Each vesicle has a diameter of approximately 50 nm, and contains as many as 10,000 molecules of a neurotransmitter substance responsible for the transmission of nerve impulse across the synapse.

The membrane of the synaptic knob on the axon side, thickened as a result of cytoplasmic condensation, is called **presynaptic membrane**. When a wave of depolarisation reaches the presynaptic membrane, voltage-gated calcium channels, concentrated at the

synapse open. Because they are 10,000 times more concentrated towards the outerside of cell, Ca^{2+} ions then diffuse into the terminal from the surrounding fluid. The Ca^{2+} ions, in some way, stimulate synaptic vesicles in the terminal to move to the terminal membrane, fuse with it and then rupture thereby expelling neurotransmitter chemicals from vesicles at the tip by exocytosis into the cleft. These neurotransmitters rapidly pass to the other side of the gap. They then combine with specific **receptor molecules** on the membrane of the target cell, which is called the **postsynaptic membrane**. By doing so, they cause a second electrical current, passing on its signal. To end the signal, the synaptic blobs reabsorb some neurotransmitters, and enzymes in the synapse neutralise others. The great advantage of a chemical synapse, compared with the direct electrical synapse, is that the nature of the messenger neurotransmitter can be different in different synapses, permitting different kinds of responses, either excitatory or inhibitory in nature. At least over 30 biochemicals (biogenic amines and derivatives of amino acids) and over 60 neuropeptides have been discovered and identified so far, that act as specific neurotransmitters.

Central Nervous System

The structures of the brain arise from its embryological components. **Prosencephalon** becomes the thalamus and hypothalamus (**diencephalon**), and the cerebral cortex, corpus striatum, hippocampus and amygdala (**telencephalon**). **Mesencephalon** becomes midbrain. **Rhombencephalon** develops into the medulla (**myelencephalon**) and the pons and cerebellum (**metencephalon**).

Human brain : The first thing to notice in the human brain after removing skull is that it is covered by tough tissue known as **meninges**. Surrounding the brain, the cranial meninges are continuous with spinal meninges and have the same basic structure and bear the same names. The outer layer is called **dura mater** (*L. hard mother*). The dura is a thick double layer of fibrous tissue, which can resist the movement of the brain that may stretch and break the blood vessels. The middle layer is called the **arachnoid** (*Gk. : like a spider's web*). It is a very thin sheet of delicate connective tissue that follows the brain's contours. The inner layer, the one close to the brain, is called **pia mater** (*L. soft mother*). It is a moderately tough membrane of connective tissue fibres that cling to the surface of the brain.

The human brain has wrinkled surface and appears as a large, soggy, pinkish grey walnut. Adult brain, on average, weighs two per cent of their body weight, growing from a quarter of its size at the time of birth. The brain reaches between 75 and 80 per cent of adult size within the first two years, and its full size at the age of 6 years.

Within the soft and delicate tissue of gelatinous consistency, are more than 100 billion (10^{10}) neurons; each can connect with perhaps as many as 25,000 other cells. Thus, there are 25,000 times 100 billion or 2.5 million billion (2.5×10^{15}) interlinked complex nerve connections, in everchanging relationships. And there are as many as ten times neuroglia cells, almost a trillion of them that support and nourish neurons.

The human brain has quite a varied structure [Fig. 10.7(a)]. A deep cleft, the **longitudinal fissure** from the centre of the brain front-to-rear, splits it into two halves or the left and right **cerebral hemispheres**. They are connected by about 10 centimetre-long bundles of densely packed nerve fibres (about 200 million), called **corpus callosum** [Fig. 10.7(b)]. The left half of brain controls the right side of body and vice versa. Other grooves divide the surface of each cerebral hemisphere into four lobes. Named for the skull bones that enclose them, they start from the forehead and move to the rear of the cerebrum: the **frontal lobe** and the **temporal lobe** at the front; and the **parietal lobe** and the **occipital lobe** at the back. A mirror image of this arrangement characterises the right cerebral hemisphere.

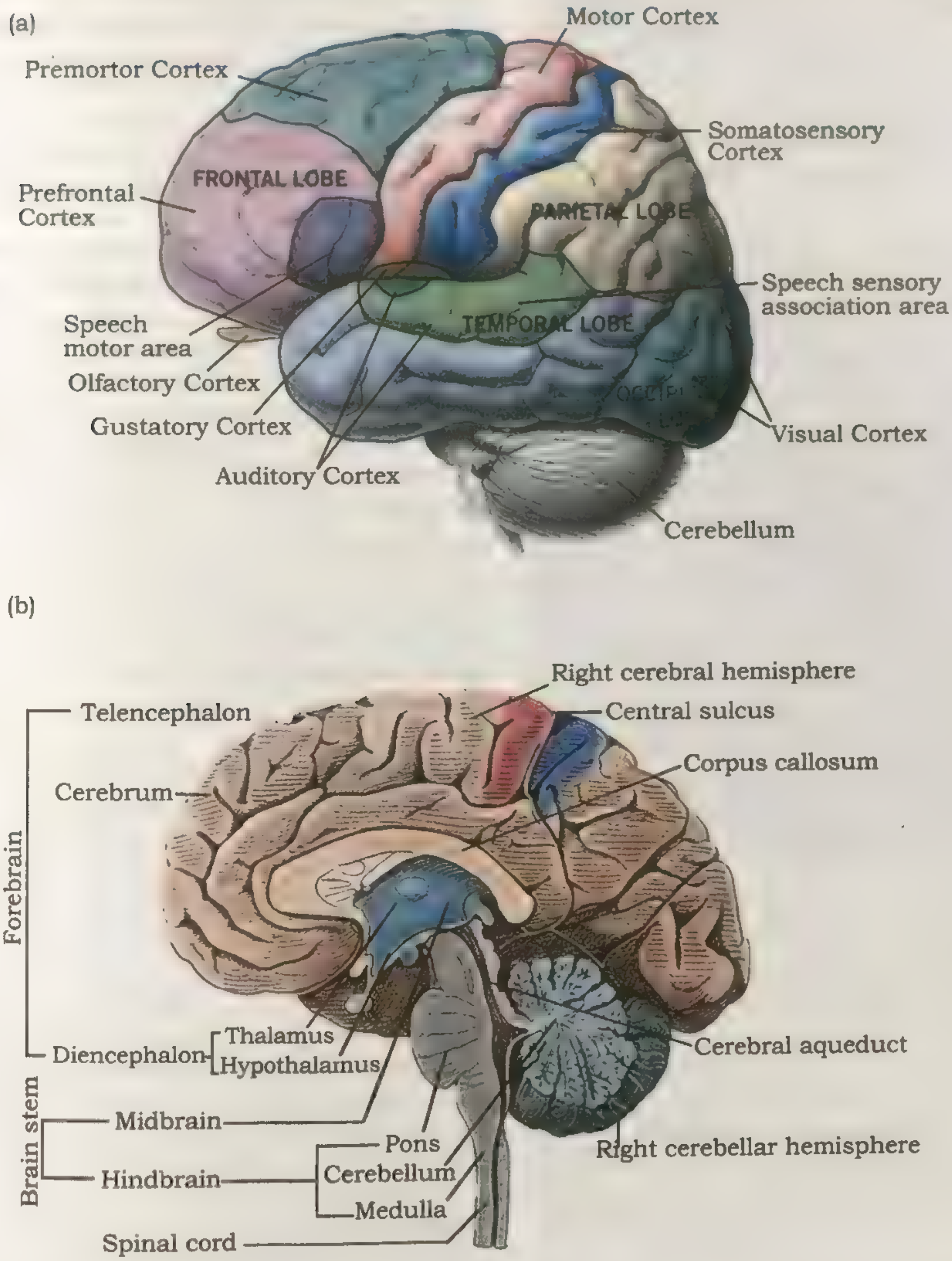


Fig. 10.7 *(a) Human brain showing major lobes*
(b) Medial aspect of adult human brain in sagittal section

Table 10.1 : Cerebral Lobes and their Major Functions

Cerebral Lobe	Major Function(s)
Frontal lobe	Inner monitoring of complex thoughts and actions, creative ideas, translation of perceptions and memories into plans of muscle movement, reality testing by judgement, intellectual insight, ability to abstract, reasoning, decision making, expression of emotions, willpower and personality.
Parietal lobe	Registration of sensory perception of touch, pain, heat and cold, knowledge about position in space, taking in information from environment, organising it and communicating to rest of brain.
Temporal lobe	Decoding and interpretation of sound, language comprehension, smell, memory and emotion.
Occipital lobe	Decoding and interpretation of visual information : shape and colour.

Each lobe is stated to specialise in certain functions (Table 10.1). The frontal lobe is where your creative ideas occur. The temporal lobe is where sounds are interpreted so that you understand what is being spoken. The parietal lobe is where feelings about touch, hot and cold and pain are registered. It is this area that allows you to accurately follow directions on map, reading a clock or dressing yourself. The occipital lobe is where your eyes see, and interpret what is seen.

Separated by a transverse deep groove, the **central sulcus**, adjacent band of **motor area** in the frontal lobe, trigger all commands to the body to move. The leading edge of the parietal lobe just behind the central sulcus, is **somatosensory area** that registers messages from the body and the senses.

Cerebral cortex : The outer surface of cerebrum, called the **cortex**, is a layer only 2-4 millimetres thick. Because the six layers of it are packed with ten billion (10^9) pyramidal, spindle and stellate neurons with a greyish brown appearance, it is referred to as **gray matter**. The cerebral cortex contains roughly 10 per cent of all neurons of brain. Much of the neural activities occur here, e.g., from the touch of a feather to the movement of an arm. Unlike mouse brain, your brain is greatly convoluted. These convolutions or folds consist of **sulci** (*sing. Sulcus* : small groove), **fissures** (large grooves), and **gyri** (*sing. Gyrus* : buldge between adjacent sulci or fissures). These greatly enlarge the surface area of the cortex. In fact, two-thirds of the surface of the cortex is hidden in the sulci and fissures. Thus, their presence triples the area of the cerebral cortex. Beneath this run millions of axons comprising nerve fibre tracts, connecting the neurons of cerebral cortex with those located elsewhere in the brain. The large concentration of myelin gives this tissue an opaque white appearance. Hence, they are referred by the term **white matter**. By examining the effect of injuries or lesions, and the effect of electrical stimulation on the behaviour, it has been possible to map roughly the location of its various associative activities on the cerebral cortex. Each area is referred to as a specialised cortex. There are three general kinds of cortex : sensory, motor and associative.

Cerebellum : To the rear of the brain and placed under the cerebrum, is the second-largest part of the brain, called the **cerebellum** that means simply "little cerebrum". Wedged between cerebral hemispheres and brainstem, cerebellum is made up of two cerebellar hemispheres. Like the cerebrum, the cerebellum has its gray matter on the outside, comprising of three layers of cells and fibres. The middle layer contains characteristically large flask-shaped **Purkinje cells**. Tree-like themselves with myriad of dendrites, purkinje cells rank among the most complex of all neurons. Three paired bundles of myelinated nerve fibres, called **cerebellar peduncles**, form communication pathways between the

cerebellum and other parts of the CNS. The **superior cerebellar peduncles** connect the cerebellum to the midbrain, the **middle cerebellar peduncles** communicate with the pons, and the **inferior cerebellar peduncles** consist of pathways between the cerebellum and the medulla oblongata, as well as spinal cord.

Cerebellum does not initiate movement but modulates or reorganises motor commands. Cerebellum's unconscious directions and cerebrum's conscious instructions determine how and when to move body parts. The cerebellum is vital to the control of rapid muscular activities, such as running, typing and even talking. All the activities of the cerebellum are involuntary, but may involve learning in their early stages.

The inside of human brain is not so densely packed, but there are all kinds of different collections of neurons, called **nuclei**, each with its specific functions. These control different body activities automatically, and you are barely aware of their activity. **Basal ganglia** is a collection of **subcortical nuclei** in the forebrain, at the base of the cortex. The largest nucleus in it is the **corpus striatum**. It regulates planning and execution of stereotyped movements. Most of the brain, though, is the cerebrum which wraps around the **thalamus**, which is a key communication link between the senses and the cortex that receives majority of incoming signals, determines their source, evaluates their importance, and integrates before passing them on to the cerebrum.

Hypothalamus : As the name implies, hypothalamus nestles at the base of the thalamus, and so of the brain. Although relatively small, just 4 grams, about 1/300 of the total brain mass is highly vascularised. It integrates and controls the visceral activities. The hypothalamus, through its connection with brain stem, maintains homeostasis and the body's internal equilibrium, specialising in involuntary behaviour control. The nuclei in it signal the body to eat, drink, get angry, keep cool, and make love and so on. Hypothalamus organises behaviour related to survival of species : fighting, feeding, fleeing and mating. It keeps body temperature at roughly 37°C by means of a complex thermostat system. It also influences respiration and heartbeat, and sends out signals to correct them when they are wrong. Through connections with the pituitary gland, the hypothalamus controls growth and sexual behaviour. It also controls many more functions.

Flared like a wish bone or fork, through extensive neural links with the cerebrum and the brain stem below, constitute what is called **limbic** (meaning lip-like) **system.** This system sends out signals to the rest of the brain and the body which have great effect on your behaviour.

Above the hypothalamus, attached to the interior tips of both forks, is almond-shaped **amygdala.** This bulge of neurons is like a defense castle controlling the moods, especially anger and rage. Various regions of the amygdala play important role in emotional behaviour, such as aggression and remembering fear. Taking its name from the Greek for "sea horse", whose shape it roughly resembles, the **hippocampus** make the swollen lower lip of the limbic fork. This remarkable organ deals with a strange mix of signals about smells and memories. The hippocampus functions as a kind of index for recall of an event with its associated memory. The hippocampus converts information from short-term to long-term memory, essential in learning. The **septum** linked to the hypothalamus contains yet another emotion centre for sexual arousal.

Brain stem

It includes the area of the brain between the thalamus and the spinal cord.

Midbrain

The **midbrain** contains four little lobes, the **corpora quadrigemina.** Its principal structures are **superior colliculi** and **inferior colliculi.** The superior pair of colliculi receive sensory impulses from the eyes and muscles of the head and control visual reflexes. For example, they control and coordinate the movement of the head and eyes, to fix and focus on an object. The inferior pair of colliculi receive sensory

impulses from the ears and muscles of the head and control auditory reflexes, such as the movement of the head to locate and detect the source of a sound.

Hind Brain

Pons, (*Latin meaning* : the bridge) forms the floor of the brain stem. It serves as a neuronal link between the cerebral cortex and the cerebellum. **Medulla oblongata**, literally meaning *oblong marrow*, is the posteriormost part that connects the spinal cord and various parts of the brain. **Reticular formation** that connects to the thalamus and major nerves in the spinal cord, is the gatekeeper to consciousness.

Spinal Cord

The spinal cord in an adult human being is 42-45 cm long and 2 cm thick in mid thoracic region, somewhat thicker in the lower cervical and mid lumbar regions, and smallest at the inferior tip, down inside a tunnel that runs down the spine. It stops growing at the age of 4 or 5 years. The spinal cord acts as the link between the brain and the nerves that stretch throughout the body. In cross-section, spinal cord consists of a H- or a butterfly-shaped central core of gray matter composed of nerve cell bodies, dendrites and synapses surrounding a central canal, and an outer layer, the white matter, whose myelin sheaths give it its characteristic white colour. The gray matter on each side of the spinal cord is subdivided into regions called horns. Those closer to the front of cord, are called **anterior (ventral) gray horn**, while those closer to the back are **posterior (dorsal) gray horn**. Between the anterior and posterior gray horns are **lateral gray horns**. Lateral gray horns are present only in the thoracic, upper lumbar and sacral segments of the cord. So, within the brain, white matter is located in the inner region, whereas in the spinal cord, the nerve fibre tracts (white matter) are located on the exterior, with gray matter in the centre.

Ventricles

There are four cavities within the brain that are called **cerebral ventricles**. Each of the two **lateral ventricles** is located in a hemisphere of the cerebrum. The **third ventricle** is a vertical slit at the mid line between the lateral ventricles. The **fourth ventricle** lies between the brain stem and the cerebellum. Extracellular fluid, continuously circulating through the subarachnoid space between the arachnoid and pia mater around the brain and spinal cord and through cavities within the brain, is called **cerebrospinal fluid** or **CSF**. It is a clear, colourless fluid, similar to blood plasma, except that it has a much lower proportion of protein and cholesterol. The entire CNS contains between 80 ml and 150 ml of CSF. The membranes in the roof of the ventricles produce CSF. It contributes to homeostasis and has several functions, including :

(a) *Protection of the delicate brain and spinal cord* by providing shock-absorbing medium. It acts to cushion jolts to CNS and lessen the impact of shock.
(b) *Buoyancy to the brain* because it is immersed in CSF, and so the net weight of the brain is reduced from about 1.4 kg to 0.18 kg. Therefore, the pressure at the base is reduced.
(c) *Excretion of waste products*. One-way flow from CSF to the blood takes potentially harmful metabolites, drugs and other substances away from the brain.
(d) *Endocrine medium for the brain* to transport hormones to other areas of the brain. Hormones released into CSF can be carried to remote sites of the brain, where they may have some action.

10.4 Peripheral Nervous System

Cranial Nerves

There are 12 pairs of cranial nerves, 10 originate from the brain stem, but all pass through foramina of the skull. The cranial nerves are designated with roman numerals, indicating the order in which the nerves arise from the brain, from anterior to posterior. Some cranial nerves contain only sensory fibres, and thus, called **sensory nerves**. The remainder contain both sensory and motor fibres and are referred to as **mixed nerves**, though a few of them are predominantly motor in function. **Motor fibres** include both somatic and autonomic efferents. First and second cranial nerves are sensory.

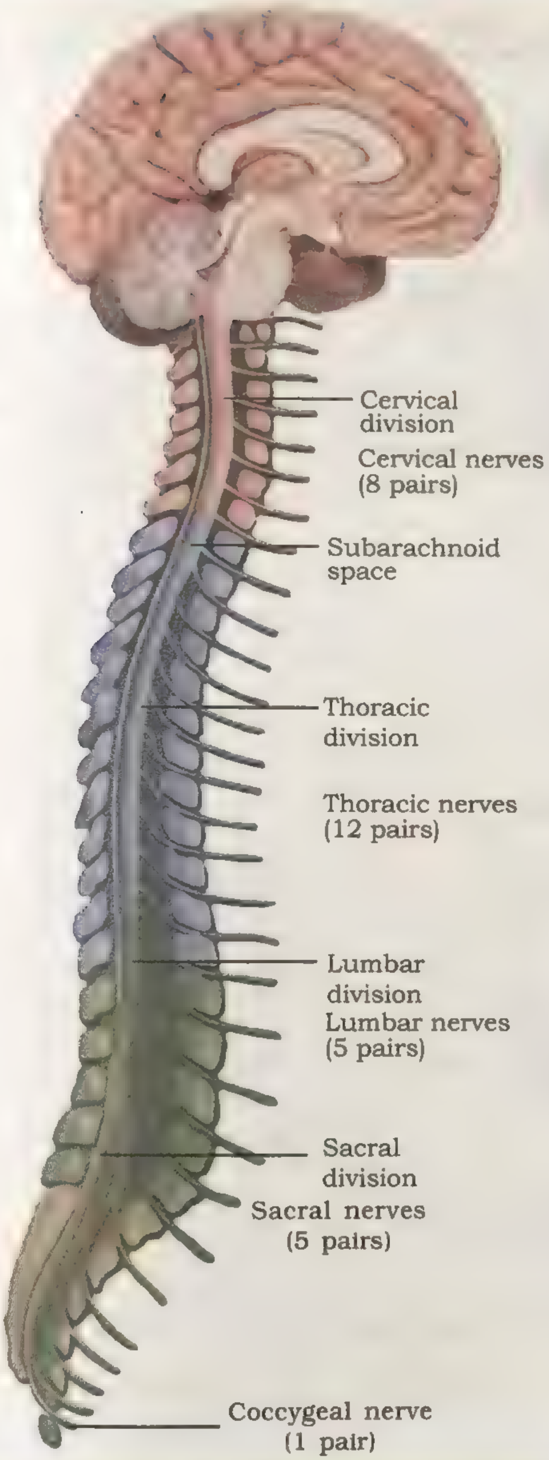


Fig. 10.8 *Spinal nerves*

Third and fourth cranial nerves originate from midbrain.

One-third of cranial nerves (V to VIII) originate from pons. **Trigeminal nerve** (V) is the largest. As the name suggests, the trigeminal nerve branches into three pairs, with sensory fibres fanning out to jaw, scalp and face. Another one-third of cranial nerves (IX to XII) originate from the side of the medulla. **Vagus** (X) nerve regulates the functions of organs in the thoracic and abdominal cavities.

Spinal Nerves

From either side of the cord arise 31 pairs of segmental spinal nerves (Fig. 10.8). Each spinal nerve joins the spinal cord at two points called **roots**, and contains both **receptor neurons** and **effector neurons**. The dorsal or posterior root contains sensory afferent fibres that transmit impulses from receptors in the periphery into the spinal cord. At the middle of each dorsal root, there is a swelling, called **dorsal root ganglion**, which contains the **sensory neurons**. The other point of attachment of a spinal nerve to the cord is the ventral or anterior root. It contains the **motor neurons** present in gray matter, and transmits impulses from the spinal cord to the effectors via motor efferent nerve fibres. There is no ventral root ganglion.

10.5 Autonomic Nervous System

The **autonomic nervous system** or ANS is auto-functioning, "self governed". It plays a major role in fine-tuning of body's internal environment, and this, in a sense, allows our overt behaviour to proceed normally. Functionally, like the voluntary somatic nervous system, the autonomic nervous system achieves its control of smooth muscles, cardiac muscles and certain glands, by both feedback loops and antagonistic control, but without conscious control of CNS. Structurally, the ANS consists of two separate output systems, the **sympathetic** and the **parasympathetic divisions** (Fig. 10.9).

The autonomic nervous system is composed of two types of neurons, a myelinated

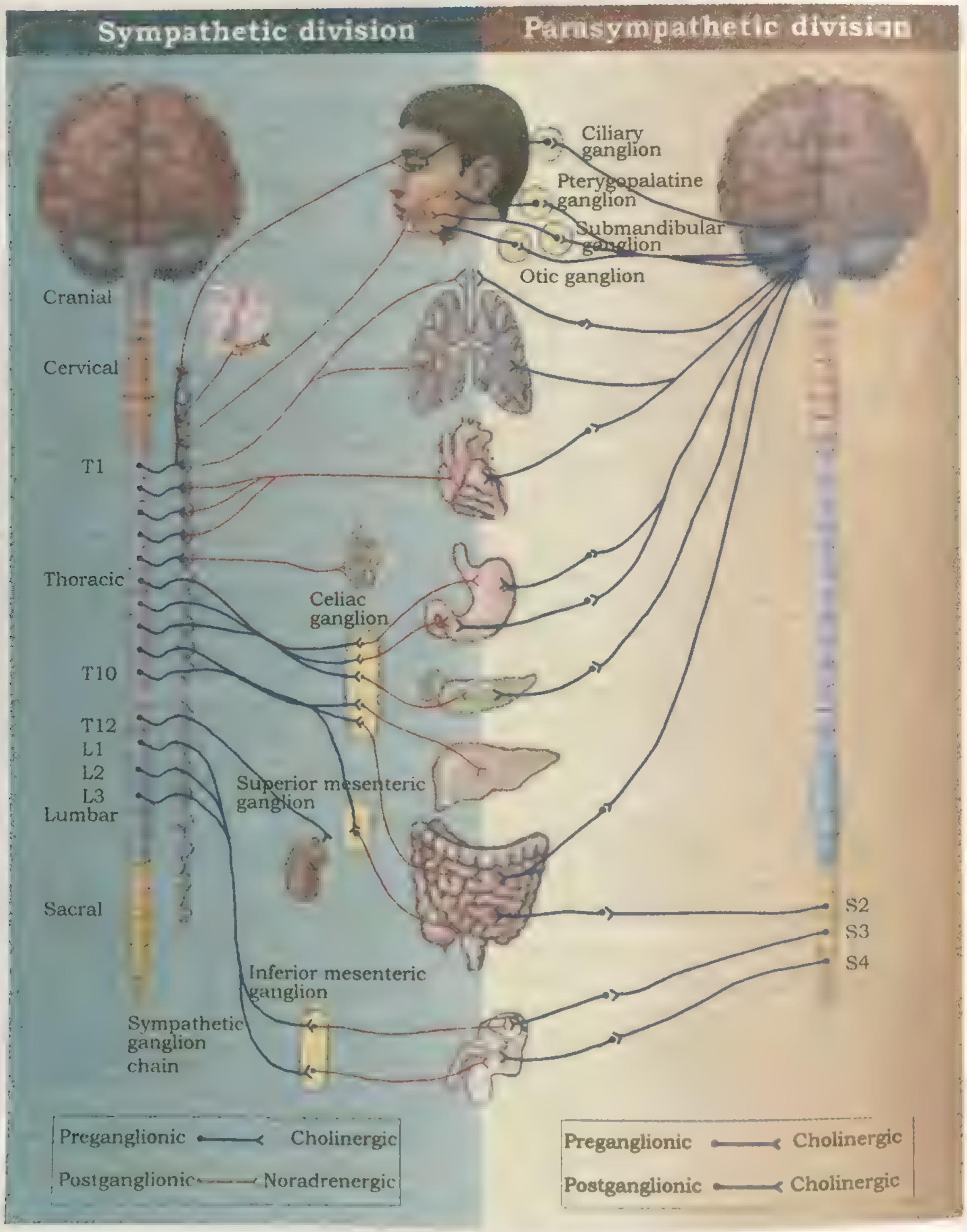


Fig. 10.9 *Autonomic nervous system*

preganglionic neuron, which leaves the ventral root of the segmental nerve before synapsing, with several unmyelinated neurons leading to the effectors. With one exception, all sympathetic preganglionic axons enter the **autonomic ganglia**, which are bulbous structures containing the cell bodies of many neurons of the sympathetic chain, but not all of them synapse there. The exception is the medulla of the adrenal gland. The cell bodies of sympathetic postganglionic (motor) neurons are situated in ganglia close to the spinal cord. Each **sympathetic ganglion** is connected to the spinal cord by a **white ramus communicans** (*pl.* rami communicantes), and the spinal nerve by a **gray ramus communicans**.

The Sympathetic Nervous System

It is made up of a network of short preganglionic axons that extend to ganglia located near the thoracic and lumbar region of the spinal cord, and of long postganglionic neurons extending from the ganglia directly to each target organ. Long preganglionic fibres of celiac ganglion is an exception. For this reason, the fibres of the sympathetic efferent neurons are also referred to as the **thoracolumbar outflow**.

The Parasympathetic Nervous System

It is made up of a network of preganglionic axons that synapse with organ-associated ganglia in the immediate vicinity of an organ, located in the cranial and sacral regions of the spinal cord, and of short postganglionic neurons extending from the ganglia to the target organ. Thus, the fibres of the parasympathetic efferent neurons are referred to as the **craniosacral outflow**.

Adjacent segmental sympathetic ganglia on each side of the spinal cord are linked together by the sympathetic tract, to form a chain of sympathetic ganglia running alongside the spinal cord. The ganglia of the parasympathetic nervous system are situated close to, or within, the effector organ. The paired sympathetic trunks lie anterior and lateral to the spinal cord, one on either side.

The neurotransmitter within the ganglion is **acetylcholine** for both sympathetic and parasympathetic nerves. However, the neurotransmitter between the terminal autonomic neuron axon and the target organ is different in the two antagonistic autonomic nervous systems. In the parasympathetic system, the neurotransmitter at the terminal synapse is acetylcholine, just as it is in the ganglion. In the sympathetic system, the neurotransmitter at the terminal synapse is either **adrenaline** or **noradrenaline**, both of which have an effect opposite to that of acetylcholine. There is one exception: the sympathetic postganglionic neuron that terminates on the sweat glands, uses acetylcholine. Thus, depending on which of the two paths is selected by the CNS, an arriving signal will either stimulate or inhibit the organ. Thus, an organ receiving nerves from both visceral nervous systems is subjected to the effects of two opposing neurotransmitters. If the sympathetic nerve ending excites a particular organ, the parasympathetic usually inhibits it. With few exceptions, organs of the body are innervated by "dual innervations", and each has a different effect.

10.6 Reflex Action : Rapid and Automatic Responses

The great majority of body functions controlled by the nervous system involve **reflexes**. Reflex actions are very rapid, automatic, stereotyped behaviour, in which some kind of stimulus evokes a specific short-lived response. Although reflex pathways involve CNS, they do not necessarily involve conscious control of the brain. Therefore, reflexes are described as involuntary actions, as no conscious awareness, thought or decision is required for their operation.

Reflex Arc

There are more than 200 reflexes "wired" into our nervous system, all following the sequence from stimulus to reflex, along specific neural pathways that make up a **reflex arc** (Fig. 10.10). The simplest reflex arc involves some specific receptor(s), afferent sensory neuron(s) towards an aggregation of nervous tissue, which may be ganglion or the spinal cord or a posterior extension of brain, and efferent motor neuron(s) from the latter to specific effector muscle fibre(s) or gland(s), and one or more intermediate or

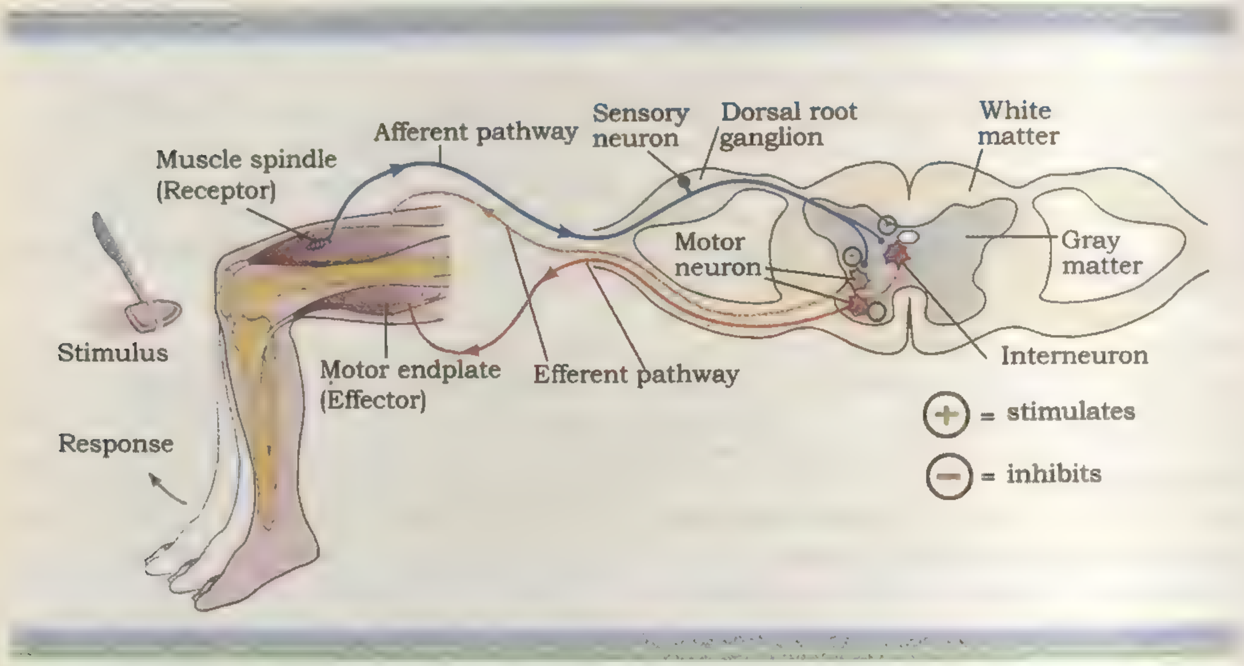


Fig. 10.10 *Knee jerk reflex.*
When the rubber mallet gives a sharp tap to the knee-cap, the muscle stretches in response to the pull of tendon. This signal is conducted along the afferent sensory axon (blue). This impulse is conducted along the axon (orange) of the extensor muscle of the quadriceps. Contraction of it causes the lower leg to extend outward abruptly in an attempt to counteract the unexpected stretch. A parallel reflex that involves a more complicated feedback loop in which interneuron synapes with a different motor neuron (red) innervating bicep flexor muscle.

relay interneuron conducting impulses from receptor to effector. Impulses can flow only in a single direction in a reflex arc.

10.7 Sensory Reception and Processing

How are environmental changes detected? In its broadest context, sensation is the conscious or unconscious awareness of external or internal stimuli. Just as you are doing in reading this page. Sensing of this sort of external environment is **extroception**. Dancers and sport persons are able to maintain their proper body position by using their internal sense of balance. Sensing of this sort of body's internal condition and position is **introception**. **Perception** is the conscious awareness and interpretation of sensations.

How do sensory receptors encode stimulus strength and (in many cases) the temporal pattern of the stimuli? The simplest example is the stretch receptor. Stretching a neuromuscular spindle produces a local depolarisation of the plasma membrane of receptor cell. When this receptor potential, also known as generator potential, reaches threshold level, it triggers an action potential in the nerve fibre.

Eye

Our paired eyes are held in the protective bony sockets of the skull, called orbits, by four rectus (superior, medial, lateral and inferior) muscles and two oblique (superior and inferior) muscles that control eye movements.

Each eye weighs roughly only 7 grams. It is composed of an array of accessory structures, and is concerned with converting light of various wavelengths reflected from objects at varying distances, and bringing the visual field to the photoreceptor cells situated in the innermost layer of eye, the **retina** [Fig.10.11(a)].

Each eyeball is composed of three concentric layers [Fig. 10.11(b)]. The outermost **sclera** is tough but elastic sheath of fibrous connective tissue, containing collagen fibres, except for the coloured part at the front. This coloured circle on your eye is called the **iris**, containing pigments that give its colour.

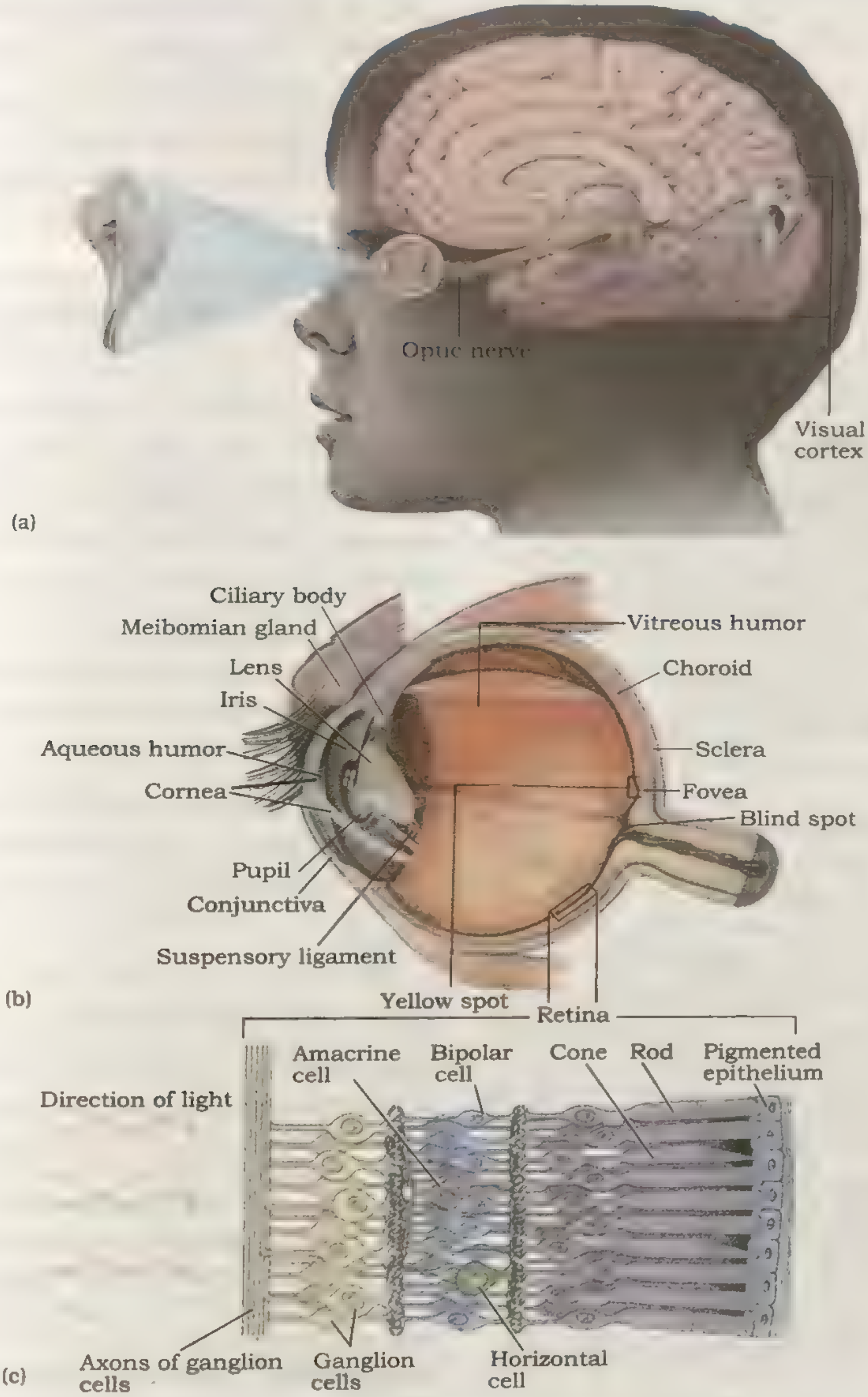


Fig. 10.11 *(a) Human eye and image formation (b) Accessory structures of human eye shown through cut section of the eyeball (c) Microscopic structure of the retina*

At the centre is the transparent zone or **pupil**. The domed **cornea** at the front is transparent, with more curved surface to act as a main structure, refracting light towards the retina. Just inside the sclera is a layer of darkly pigmented tissue, the **choroids**, rich in blood vessels. It prevents internal reflection of light within the eye. These reflections reduce resolution, but increase sensitivity by sending the unabsorbed light back through the receptor layer. This mirror-like layer, called **tapetum**, accounts for the way a cat's eye seems to glow in the dark. Just behind the junction between the main part of the sclera and the cornea, the choroids become thicker and has smooth muscles embedded in it. This portion of the choroids is called **ciliary body**. Tears secreted by the lacrimal glands lubricate the exposed surface of the eye, including the **conjuctiva**, the thin transparent layer continuous with the epithelium of eyelids, which covers the cornea except in the centre. Embedded in each tarsal plate of the eyelids is a row of elongated modified sebaceous glands, known as **Meibomian glands**. Their oily secretion helps keep the eyelids from adhering to each other.

The iris also contains radial bands and a ring of circular smooth muscles. It is to control the amount of light that reaches the photosensors at the back of the eye, just as the diaphragm of the camera controls the amount of light reaching the film. Contraction of radial muscles and relaxation of the circular muscles cause dilation of the pupil.

A tiny circular area, about 6 mm in diameter in the retina, is **yellow spot** or **macula lutea**, where the vision is sharpest. If we accidentally focus on intense light sources, such as sun, it will damage macula lutea. This acts as a filter over **fovea**, a tightly packed array of specialised photosensor-receptor cells in the centre of the circle. This is placed above the **blind spot**, the area from where the optic nerve emerges.

The **lens**, composed of crystalline protein, is suspended behind the pupil by a **suspensory ligament** attached to the ciliary body. The lens and its suspensory ligament divide the cavity of the eyeball into two chambers. The chamber between the cornea and lens is filled with a clear watery fluid, the **aqueous humor,** that is finally drained into the blood through canal of Schlemm. The chamber behind the lens is filled with a clear semi-solid gelatinous material, the **vitreous humor**, supporting the eyeball.

The retina is composed of several layers of cells, each containing a characteristic type of cell [Fig. 10.11(c)]. First, there is the photoreceptor layer containing the photosensitive cells, the **rods**, and **cones**, partially embedded in the microvilli of pigmented epithelium cells of the choroids.

These photoreceptor cells are the sites in retina, where the primary processes during image formation take place. The rod cells are more sensitive towards light as compared to cone cells. Rods are used for vision in dim light (scotopic vision), having no ability to detect colour. Whereas, cones are used for bright light vision (photopic vision), with the ability to make coloured image of the object. The photosensitive chemical substance or the pigment in rods, is called **rhodopsin** and those in cones are called **cone pigments**, specific for the basic colours blue, green and red. Thus, cones are of three different types, short wavelength-sensitive (blue) cones, medium wavelength-sensitive (green) cones, long wavelength-sensitive (red) cones.

Next is the intermediate layer containing short sensory **bipolar neurons**. Bipolar cells, in turn, synapse with the **retinal ganglion cells**, whose axons bundle together as the optic nerve. The relationship of receptors to bipolar cells to ganglion cells is 1:1:1 within the fovea. Outside the fovea, however, processing of visual information can occur within the retina because often several receptor cells synapse with a single bipolar cell, and several bipolar cells synapse with a single ganglion cell. Besides this convergence of information, **horizontal** and **amacrine cells** enable lateral transfer of information from pathway to pathway. Each horizontal cell receives synapses from many receptor cells and synapses onto many bipolar cells and other horizontal cells. Amacrine cells both receive synapses from and

synapse on to bipolar cells. They also synapse on to many ganglion cells. This allows a certain amount of processing of visual information to occur before it leaves the retina, for instance, these cells are involved in lateral inhibition. This lateral flow of information sharpens the perception of contrast between light and dark patterns falling on the retina. Note that the retina is arranged anatomically in reverse order from what might be expected. The receptor cells are in the back of the retina, and light must pass through the nerve cells to reach them.

Accommodation (focussing) is the reflex mechanism by which light rays from objects at various locations in the near visual field are brought to focus on the retina. Altering the shape of the lens does this. In bright light the circular muscle of the iris contracts, the radial muscle relaxes, the pupil becomes smaller and less light enters the eye, preventing damage to the retina. In dim light, the opposite muscular contractions and relaxations occur. In the dark of night, your pupil may become up to 16 times bigger. In the light, the added advantage of reducing the pupil size is that it increases the depth of focus of the eye, so that any displacement of the photosensors in the retina will not impair the focus.

Light rays from distant objects (>6 metres) are parallel when they strike the eye. Light rays from near objects (<6 metres) are diverging when they reach the eye. In both cases, the light rays must be refracted or bent to focus on the retina and refraction must be greater for light from near objects. The normal eye is able to accommodate light from objects, from about 25 cm to infinity. With the involuntary ciliary muscles at rest, the flatter lens has the correct optical properties to focus distant images on the retina, but not close images. The state of contraction of the ciliary muscles changes the tension on suspensory ligaments. This acts on the natural elasticity of the lens, which causes it to change its radius of curvature, and thus, the degree of refraction. As the radius of curvature of the lens decreases, it becomes thicker, round up and amount of refraction increases. It is the tension of the suspensory ligaments applied to the lens which determines the shape of the lens. When the circular ciliary muscles are relaxed and the suspensory ligament becomes taut, the lens is pulled into a flattened shape suitable for focussing distant objects, decreasing the refraction. When the tension is decreased, the circular ciliary muscles are contracted and the suspensory ligaments slack, consequently the lens becomes a more spherical shape suitable for focussing objects.

The image produced by the lens of eye on the retina is inverted and reversed. However, objects are perceived the right way up because of the way in which the brain interprets the images.

The region of the environment from which each eye collects light, is called the **visual field**. Since both our eyes are frontally placed, there is an overlap between the visual fields of each eye. This is called **binocular vision**.

Ear

Auditory mechanoreceptors assist in detection of sound wave and transducing them into nerve impulses. These also help in keeping balance by controlling the muscles needed to keep the body steady and avoiding the toppling over.

Human ear consists of three sections specialising in different functions (Fig. 10.12). The flap of elastic cartilage tissue on the side of your head is only the entrance to the ear. This outer ear or pinna is simply a sound-gathering trumpet. Its technical name is the **auricle**. The eardrum or **tympanic membrane** covers the outer end of the curved ear tube, external auditory meatus or canal in the temporal bone. In this canal, a profusion of hair and secretions of 4,000 specialised **cerumenous glands** act as a flypaper trap for insects, dust and other potential irritants. Further, the ear wax guards against infection, particularly when you swim in dirty water. The tympanic membrane vibrates in response to pressure waves travelling down the auditory canal. The chamber of the middle ear, an air-filled cavity, lies on the other side of the tympanic membrane. The middle ear (tympanic cavity) is open to the throat at the back of the mouth through the **Eustachian tube** in such

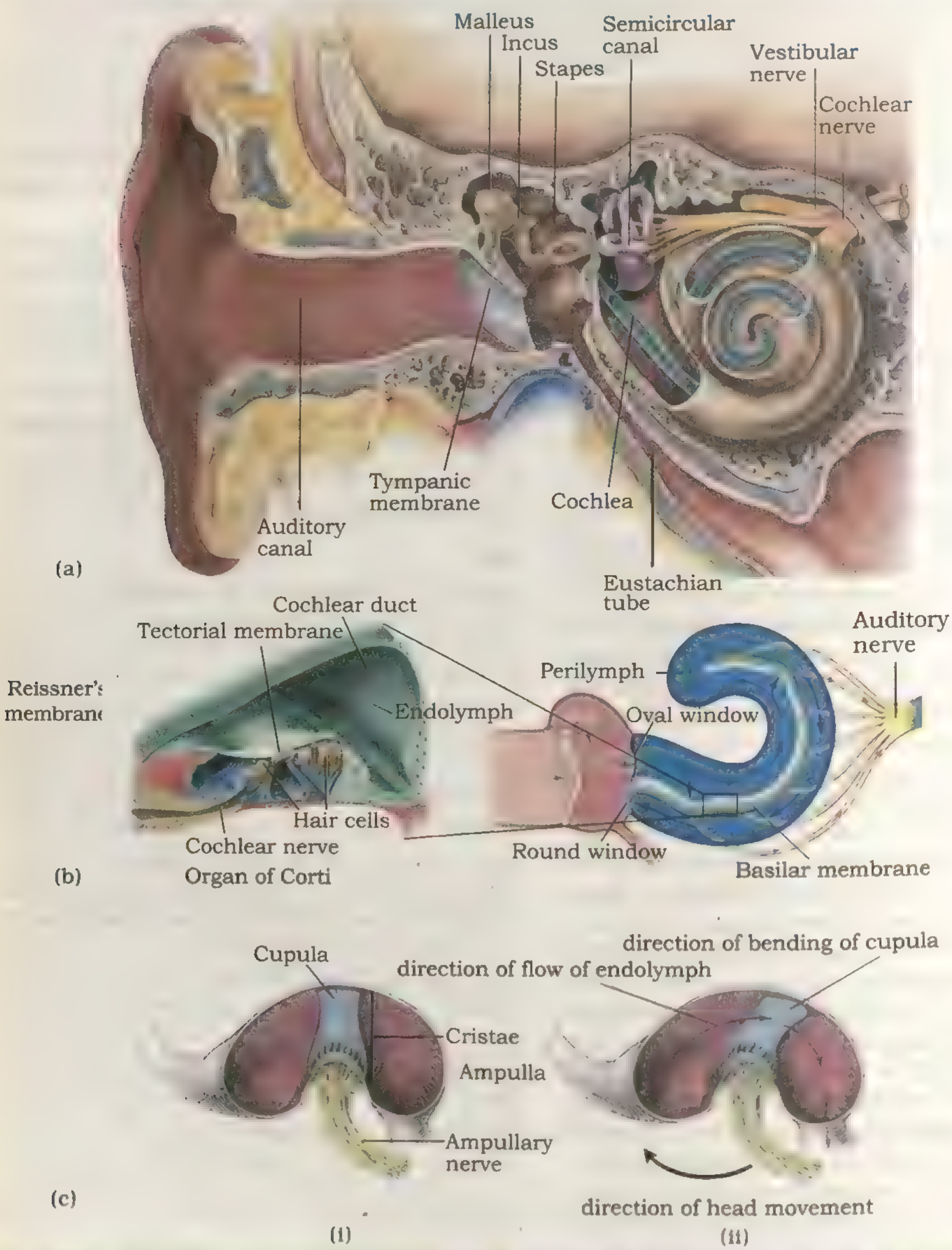


Fig. 10.12 *(a) Internal structure of human ear (b) Inside view of cochlea (c) (i) Semicircular duct showing position of a cristae with head in still position and (ii) position of cristae when head moves*

a way, that there is no difference in pressure between the middle ear and the outer ear.

The bean-sized middle ear contains three delicate bones, called the **ear ossicles**. These are known by Latin names, which have simple descriptive English equivalents: the **malleus** (hammer), **incus** (anvil) and **stapes** (stirrup). These ossicles act in concert as a lever system, increasing the force of the vibration, a kind of mini amplifier. The handle of malleus is attached to internal surface of the tympanic membrane and strikes against the incus. The third in line of this chain of bones, the stapes pushes against another membrane, the **oval window**. This series of bones makes the vibrations strong enough to relay to the fluid in the inner ear. Directly below the oval window is another opening, the **round window** [Fig.10.12(b)]. The intermediate bone in the series "incus" serves as a pivot point. When the tympanic membrane moves in, the lever action of the ossicles pushes the stapes and the oval window bulges into the inner ear. Because the oval window is smaller than the tympanic membrane, vibration against it produces more force per unit area of membrane, almost about 20-fold. The membrane covering the oval window is the door to the inner ear, where hearing actually takes place.

When the tympanic membrane moves out, the stapes and the oval window are also pulled out. In this way, pressure waves in the auditory canal are converted into pressure waves in the fluid-filled inner ear, also called the **labyrinth**. Pressure waves are transduced into action potentials in the inner ear. The fluid-filled spiral chamber of the inner ear is shaped like a narrow snail shell and is called **cochlea**. It makes almost two and three quarter turns around a central bony core. Cochlea is composed of three parallel fluid-filled canals separated by two membranes, **Reissner's membrane** and the **basilar membrane**. The canals are vestibular canal, median canal and tympanic canal. Both the vestibular and tympanic canals contain **perilymph**, a fluid similar to cerebrospinal fluid. And the two canals are connected at the extreme end of the cochlea via a small hole, the **helicotrema**. The median canal contains **endolymph**, which is chemically similar to intracellular fluid.

Receptors for auditory sensations are tiny sensory hair cells that line the basilar membrane. These **hair cells** do not project out into the fluid filling the cochlea. Instead, they are covered with another delicate and flexible gelatinous membrane, called the **tectorial membrane**. The basilar membrane, sensory hair cells and tectorial membrane make up the smallest unit of the ear, called the **organ of Corti**, first described by Italian microscopist, Alfonso Corti (1822-1888). Sensory hair cells inside the ear resemble tracts left in the sand by truck tires. The cochlea contains 16,000 to 24,000 hair cells arranged in four rows. In three of the rows, the hairs form V-shaped patterns. In the fourth row, the hair stand in a straight line. Each hair cell has up to 100 hairs. When sound vibrations pass through the oval window, they create waves in the lymph fluid of the cochlea, like sea wave in a tidal current. The waves cause the basilar membrane to ripple. This movement bends the hair cells, pressing against the tectorial membrane and setting off nerve impulses in their associated afferent neurons. More than 30,000 neurons and nerve fibres emerging from these, convey the electrical signals to the brain, just 2 cm away via **auditory** (vestibulocochlear) nerve. The basal ends of hair cells synapse with fibres of cochlear branch. When the waves reach the round windows of the cochlea, they die away.

Above the cochlea, there are three tiny delicate organs, collectively called **vestibular system**. The vestibular system helps you to keep your balance, which is arguably more important for survival, and we owe our sense of orientation, acceleration and rotation to this system. One of the structures, called **semi-circular canals**, consists of three C-shaped fluid-filled loops. They are oriented in a different plane, at right angles to the other two, pointing up-down, side-side and front-back. One detects up-and-down motion, another lateral motion, and the third forward motion. Two other structures, near the inner ear's semi-circular canal and cochlea, record changes in the position of the head. Whichever way the head moves, fluid swirls inside at least in one

of the semi-circular canals. At one end of each canal is a bulge, the **ampulla**. Inside it is a jelly-like lump, the **crista** [Fig.10.12(c)]. The long cilia from many cells are grouped together in a bundle that is covered with a gelatinous coating. Such a bundle is called **cupula**. These are **utricle** and **saccule**. The utricle and saccule detect movements in a straight line and keep track of the position of the head.

Each utricle and saccule has a small-thickened region called **macula**, a patch of hair cells with their tips embedded in a jelly-like membrane. Inside the membrane, and piled on top of it, are microscopic calcium carbonate crystals, called **otoliths** (*oto* : ear, *lithos* : stone) or **otoconia** (*sing.* otoconium) that extend over the entire surface of otolithic membrane. These tiny crystals respond to the pull of gravity to any movement of the head.

Balance is not a single sense. It is a continuous body mechanism that processes inputs from various senses, analyses these in the brain, and sends messages to the muscle. The input comes from four main sources. First are two sets of sensors found deep inside each ear. Second are the microscopic stretch and strain gauges in the muscles, tendons and joints around the body. They allow us to know the position of the head, neck, body and limbs. Third is the skin, which feels touch and pressure according to how gravity pulls. Fourth are the eyes, which see verticals and horizontals, and so judge the angle of the head. The cerebellum processes all these data and coordinates muscle movement in conjunction with the cortex and sends signals to the muscles to adjust.

Nose

The nose contains mucus-coated **olfactory (smell) receptors**, over 20 million in number (Fig. 10.13). The smell molecules of the scent given off by a flower must vaporise so that it can be wafted up the nostrils. Olfactory epithelium consists of three principal kinds of cells :

(i) olfactory bipolar neurons
(ii) supporting columnar epithelium of the mucus membrane, and
(iii) Bowman's glands.

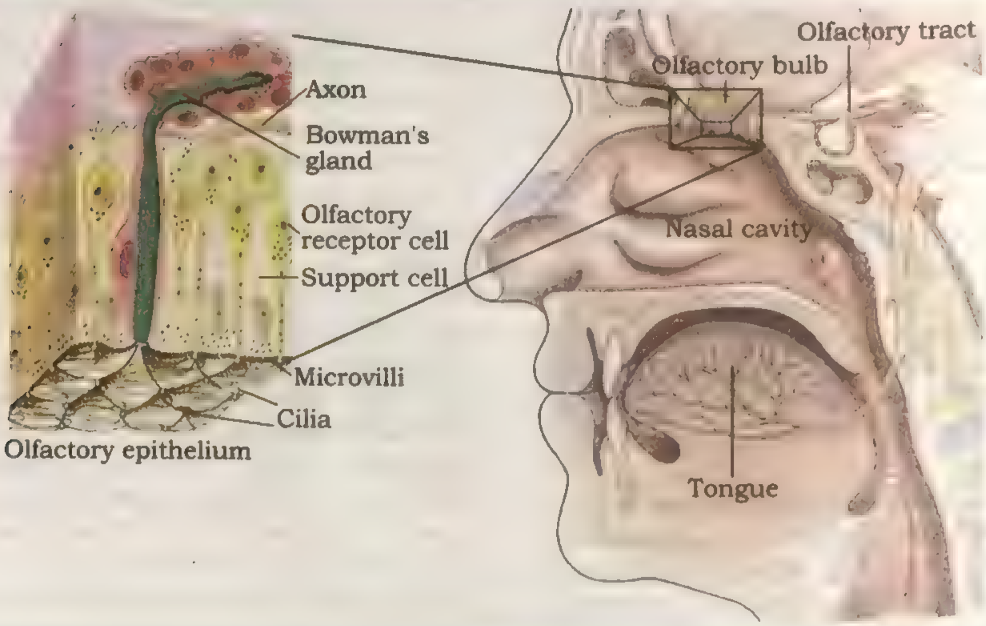


Fig. 10.13 *Human nose showing olfactory bulb. Inset: Magnified view of olfactory epithelium*

Olfactory epithelium differs from the receiving ends of your other senses, in that its neurons extend from the outside environment directly into a pair of broad bean-sized organs, called **olfactory bulb**, which are extensions of the brain's limbic system. Twenty or so tiny sensory cilia, the olfactory hair on the ends of each receptor cell extend from the olfactory epithelium into the layer of mucus. The dendrites of bipolar olfactory neurons end in olfactory hair. The length and thickness of these cilia vary. The tips of some receptors stick up farther than others. The mucus produced by **Bowman's glands** absorbs odoriferous substances that stimulate the receptors on the cilia. Inside the nose, these glands release fluids to get rid of the irritating substances. Bundles of unmyelinated axons of the olfactory receptors unite to form olfactory nerve (first cranial nerve), which carry olfactory nerve impulses to the olfactory bulb, a relay station. The number of receptors stimulated indicates the strength of smell.

In addition to smell receptors, your nose, mouth and tongue contain a network of nerves that form the trigeminal nerve (fifth cranial nerve). This nerve, also known as **Dentist's nerve**, reacts to messages of pain. The brain combines the trigeminal signals with those of smell to identify some odours, when exposed to irritants such as ammonia or vinegar. The trigeminal can protect by warning about harmful chemicals in the air.

Tongue

Both nose and tongue detect dissolved chemicals. The chemical senses of gustation (taste) and olfaction (smell) are functionally similar and interrelated. There are four basic types of taste : **sweet**, **sour**, **salty** and **bitter** – each detected in a distinct region of the tongue. All other "tastes", such as chocolate, pepper, are combinations of these four, modified by accompanying olfactory sensations. The basic tastes are associated with specific molecular shapes or charges that bind to separate receptor molecules.

The tongue detects tastes through tiny organs, called **taste buds**, containing **gustatory receptors**. Each taste bud, may contain as many as 50 gustatory receptor cells. A single gustatory receptor cell is exposed to the external surface through an opening in the taste bud called the **taste pore**. Although each receptor cell is more responsive to a particular type of substance, a broad range of chemicals can actually stimulate it. With each taste of food or sip of drink, the brain integrates the differential input from the taste buds and a complex flavour is perceived.

SUMMARY

The evolution of the nervous system has involved the extensive elaboration of network of associative interneurons in the brain. In the more advanced vertebrates, this associative activity is increasingly centred in the forebrain. The midbrain serves as a conduit, linking the hindbrain to the forebrain.

A neuron is a cell with an excitable membrane. An excitable membrane is created when the sodium-potassium pump actively pumps Na^+ ions out across the membrane and K^+ ions in. Because this membrane is only slightly permeable to Na^+ or negatively charged anions, but is permeable to K^+ ions, a net negative charge within the cell results.

A nerve impulse is initiated by depolarisation of an axonal membrane. It propagates because the opening of some Na^+ ion channels facilitates the opening of other adjacent channels, causing a wave of depolarisation to travel

down the axonal membrane. All impulses traversing a given neuron have the same amplitude, differing only in the frequency of impulses.

Messenger chemicals, called neurotransmitters and neuropeptides, pass across a synaptic cleft and interact with channels and/or receptors in the membrane of another neuron or of muscle cells. They either open Na^+ ion channels and depolarise the postsynaptic membranes, an "excitatory" response, or open K^+ channels and hyperpolarise the postsynaptic membranes, an "inhibitory" response. Synapse, the area of contact between one neuron and another neuron or a muscle cell, transfers information in neuronal communication.

Human nervous system consists of the central nervous system comprising the brain and the spinal cord, and the peripheral nerves coursing outside the central nervous system. Three main divisions of the human brain : forebrain, midbrain and hindbrain, can be recognised during its development. For the forebrain, the cerebrum consists of two cerebral hemispheres connected by fibre tract called corpus collasum. Different areas of cerebral cortex specialise in different sensory, motor and associative functions. Inside the forebrain, the posterior and upper region has thalamus, a relay station for nerve impulses destined for the cerebral context, and the lower region has the hypothalamus, the main regulator of homeostasis and many vital functions. The midbrain has tectum on its surface and tegmentum at the base. The nuclei in it control muscle tone and motor activities. The hindbrain has a dorsal portion, the lesser brain called cerebellum. It regulates the maintenance of muscle tone, posture and equilibrium. The region between the thalamus and spinal cord is referred to as brain stem. In the medulla oblongata, there is a complex network, called reticular formation, that is the gateway of consciousness. Towards the inside of the forebrain is a collection of neuronal groups of cells and fibres, known as the limbic system. Part of it is attached to the olfactory lobes and is concerned with smell. Much of the remainder appears to be involved with emotional behaviour, such as aggression and fear, and possibly with learning and memory as well.

Twelve pairs of cranial nerves and 31 pairs of spinal nerves comprise the somatic peripheral nerves in human nervous system. Afferent and efferent fibres conduct impulses, respectively, from and to the peripheral tissues. These can be sensory, motor or mixed. Unlike brain, the spinal cord has gray matter inside and white matter surrounding it.

Autonomic pathways control unconscious involuntary behaviour via two sets of connections to each target, one from the sympathetic system, the other from the parasympathetic system. Sympathetic connections rouse in preparation for high activity, the parasympathetic system restores calm. Smooth muscles, cardiac muscles and glands are directed by antagonistic command from nerve pairs of the autonomic nervous system.

Information about the external environment is collected by sensory neurons and, in simple reflex circuits, it is passed to motor neurons quickly and automatically. Most reflex circuits, however, have interneurons that first integrate and process information from sensory neurons, before passing it on to target cells.

Human eye is designed like a lens-focussed camera. The fovea at the centre of the retina transmits a point-to-point image to the brain. Vision uses a variety of pigment as a primary photoreceptor.

Human ear responds to the rapid variations in air pressure that accompany sound. The variations move the tympanic membrane, which transfers the vibrations to the cochlea, where they set the basilar membrane into motion. Different regions of the basilar membrane vibrate best at different

frequencies, from which the brain infers pitch. The semi-circular canals register acceleration, while the otoliths indicate orientation relative to gravity.

The most sensitive chemical receptors are the taste and smell receptors. Taste receptors in our tongue respond specifically to sweet, sour, salty and bitter molecules, but are less narrowly tuned. Odour receptor types are much more numerous, each kind responding when its membrane receptors bind to parts of odour molecules.

EXERCISES

1. Which statement about olfaction is not true?
   (a) Dogs are unusual among mammals, in that they depend more on olfaction than on vision, as their dominant sensory modality.
   (b) Olfactory stimuli are recognised by the interaction between the stimulus and a specific macromolecule on olfactory hairs.
   (c) The greater the number of action potentials generated by an olfactory receptor, the greater the intensity of the perceived smell.
   (d) The perception of different smells results from the activation of different combinations of olfactory receptors.
2. The membrane that gives us the ability to discriminate different pitches of sound is the :
   (a) round window
   (b) tympanic membrane
   (c) tectorial membrane
   (d) basilar membrane
3. The region of the vertebrate eye, where the optic nerve passes out of the retina, is called the
   (a) fovea
   (b) iris
   (c) blind spot
   (d) optic chaisma
4. The colour in vision results from the :
   (a) different absorption of wavelengths of light by different classes of rods.
   (b) ability of each cone to absorb all wavelengths of light equally.
   (c) lens of the eye acting like a prism and separating the different wavelengths by light.
   (d) three different isomers of opsin in different classes of cone cells.
5. During accommodation for near vision :
   (a) images from the distant objects are focussed behind the retina.
   (b) the focussing power of the lens is increased.
   (c) the sympathetic nerves to the eye are activated.
   (d) the pupil does not constrict.
6. The all-or-none principle states that :
   (a) the properties of an action potential are independent of the strength of the depolarising stimulus.
   (b) all stimuli will produce action potentials.

(c) all graded potentials will generate action potential.
(d) any cell membrane can generate and propagate an action potential if stimulated to threshold.

7. The loss of positive ions from the interior of a neuron produces :
(a) depolarisation
(b) threshold
(c) hyperpolarisation
(d) action potential

8. Which of the following describe the largest amount of the human cerebral cortex?
(a) the primary somatosensory cortex
(b) the temporal cortex
(c) association cortex
(d) the occipital cortex

9. Which statement about the autonomic nervous system is true?
(a) The sympathetic division is afferent, and the parasympathetic division is efferent.
(b) Each pathway in the autonomic nervous system includes the neurons, and the neurotransmitter of the first neuron is acetylcholine.
(c) The cell bodies of many sympathetic preganglionic neuron are in the brain stem.
(d) The cell bodies of most parasympathetic postganglionic neurons are in or near the thoracic and lumbar spinal cord.

10. Which statement is not true?
(a) In the spinal cord, the white matter contains the axons conducting information up and down the spinal cord.
(b) The limbic system is involved in basic physiological drives, instincts and emotions.
(c) The vast majority of the nerve cell bodies in the human nervous system are contained within the limbic system.
(d) In human, a part of the limbic system is necessary for the transfer of short-term memory to long-term memory.

11. Answer true or false to the following :
The left cerebral hemisphere :
(a) receives most modalities of sensory information from the right side of the body.
(b) is usually larger than the right.
(c) is the dominant cerebral hemisphere in most individuals.
(d) is connected to the right by the corpus callosum.
(e) contains the main areas for the understanding and production of speech in most individuals.

12. Distinguish between :
(a) afferent neurons and efferent neurons
(b) rods and cones
(c) resting membrane potential and action potential
(d) impulse conduction in a myelinated nerve fibre and unmyelinated nerve fibre
(e) aqueous humor and vitreous humor
(f) blind spot and yellow spot
(g) cranial nerves and spinal nerves.

13. What is the primary function of the neuroglia cells? What special structure is produced by Schwann cells?
14. How does a wave of depolarisation spread along a nerve fibre?
15. What is a synapse? How does the nerve impulse cross the synapse?
16. What is the action potential of a neuron? Do all neurons possess the same action potential?
17. Why is the mode of conduction of electrical impulse along the myelinated neuron advantageous to a non-myelinated neuron? What is this type of conduction called?
18. (a) Make a clearly labelled diagram of the inner ear of a human being.
    (b) Describe how each of the following is achieved in us :
    (i) hearing (ii) balance
19. Are rods and cones evenly distributed over the entire surface of the retina? Why or why not? At which point on the retina is a point-to-point image formed?
20. Blind spot in the eye is devoid of the ability of vision. Why is it so?
21. If a strong odour is smelled continuously for sometime, the sensation of that weakens. Justify.
22. Which parts of the nervous system participate in the maintenance of balance and coordinated body movements?
23. What is a reflex? What units of the nervous systems are involved with a typical vertebrate reflex arc?
24. Which nerve tract connects the right and left hemispheres of the cerebrum? Into what four lobes is each hemisphere divided?

Chapter 11

Chemical Coordination in Animals

You have learnt in Chapter 10 that the nervous system orchestrates a symphony of rapid and precise activities. Actually, the effective regulation of body's functions requires not only the constant modulation and integration by the nervous system, but also chemical control by the endocrine system. However, there are some basic differences between the two controlling systems. You can recall that the nervous system acts speedily and quickens the speed of action of the responding tissue. For example, the nerve impulse moving as high as 100 metre per second along the nerves, quickens the response of skeletal muscles whose response time is only milliseconds. But the response of the target tissue to the action of hormones requires seconds or minutes or even more time. Besides, axon in a motor nerve induces only a single muscle or its fraction, whereas hormones stimulate all the sensitive cells of the target tissue. In this chapter, you will know about the human endocrine system and functions of their hormones, including their role as chemical messengers, and regulators. Also, a section will be devoted on hypothalamo-hypophysial axis and feedback controlling mechanism. At the end, you will be informed about effects of hormonal imbalance and related disorders in humans. Still, the two systems operate in a coordinated fashion on many occasions. Above all, many important functions of the endocrine system are under the control of nervous system. The two systems are often collectively referred to as **neuroendocrine systems**.

Endocrine glands (*Gk. endo* : within, *krinein* : to secrete) secrete the chemicals, called **hormones** (= to excite), into the blood, which then transport these to the target tissues located away from the site of secretion.

11.1 Human Endocrine System

The major endocrine glands of human body and their hormones in female and male are depicted in Figure 11.1.

Pituitary : the Conductor of Endocrine Symphony

The pituitary is pinkish pea-sized gland, about 1.3 cm in diameter, weighing only 0.5 g and is attached to the hypothalamus via a stalk,

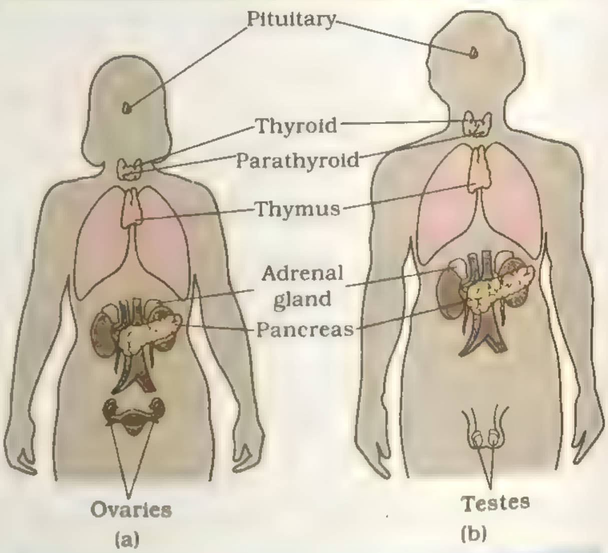


Fig. 11.1 *Endocrine system of human (a) female and (b) male*

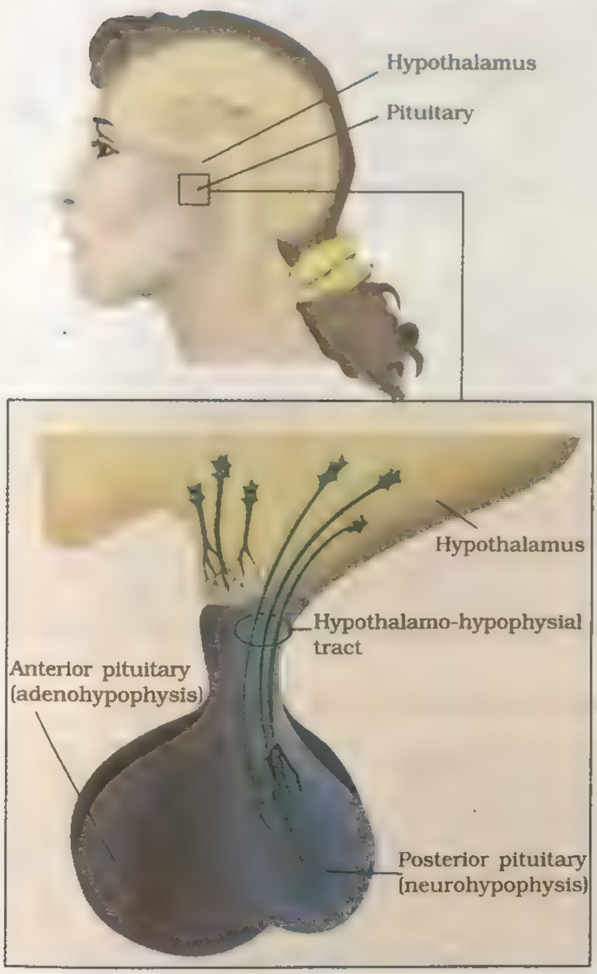


Fig. 11.2 *The pituitary gland and the hypothalamo-hypophysial axis*

called the **infundibulum**. This complex organ of human body is the source of chemicals that play a key role in many functions. The pituitary gland has two anatomically and functionally separate lobes (Fig. 11.2). The much larger **anterior lobe** or **adenohypophysis** produces a cluster of hormones. The smaller **posterior lobe** or **neurohypophysis** stores two hormones secreted by hypothalamic neurons. A third region, called the **intermediate lobe** or **pars intermedia**, atrophies during foetal development and is smaller in adults.

The anterior lobe of the pituitary is connected to the hypothalamus by portal blood vessels, only a few millimetres long. Through these vessels pass a group of regulating hormones, which are produced in the hypothalamus. These **releasing** or **inhibiting hormones** regulate and coordinate the anterior lobe of the pituitary to initiate the production or suppression of specific hormones (Table 11.1).

For each releasing hormone secreted by the hypothalamus, there is a corresponding hormone synthesised by the anterior lobe of the pituitary. When the pituitary receives a releasing hormone from the hypothalamus, it responds by stimulating cells in it to secrete the pituitary hormones. Five principal types of anterior pituitary cells have been identified. These secrete seven major hormones (Table 11.2).

Prolactin is unique among the pituitary hormones, as it is under predominant inhibitory control from hypothalamus. The controlling agent is neurotransmitter dopamine, produced by tubero-infundibular neurons. Unmyelinated nerve fibres originating from neuronal cell bodies located within supraoptic and paraventricular nuclei of the hypothalamus form the **hypothalamo-hypophysial tract** within the pituitary stalk. These neurons synthesise predominantly two nanopeptide hormones : **vasopressin** and **oxytocin**, respectively, which are then transported as neurophysin-proteins bond secretary granules down the nerve fibres.

The principal action of vasopressin (a vessel pressure effect) is to stimulate the reabsorption of water from the distal convoluted tubules and collecting ducts of the kidney, thereby reducing urine volume and conserving body fluid. Because of this antidiuretic effect, it is also referred to as the **antidiuretic hormone (ADH)**. Typical levels of vasopressin play only a minor role in regulating blood pressure by contracting arteriolar smooth muscle. When you feel thirsty or there is dehydration, it results in increase in osmolarity of the blood above a physiological set point.

Table 11.1 : Releasing or Inhibiting Hormones of Hypothalamus and their Roles, Factors and Specific Hormones they Control

Releasing or Inhibiting Hormone	Control and Regulation of Specific Hormone Secretion
Thyrotropin releasing hormone (TRH)	stimulates thyrotropin stimulating hormone release
Growth hormone releasing hormone (GHRH)	stimulates growth hormone release
Growth hormone inhibiting hormone (GHIH)	inhibits growth hormone release
Gonadotropin releasing hormone (GnRH)	stimulates release of follicle stimulating hormone and luteinising hormone
Prolactin releasing hormone (PRH)	stimulates prolactin release
Prolactin inhibiting hormone (PIH)	inhibits prolactin release
Adrenocorticotropic hormone releasing hormone (CRH)	stimulates adrenocorticotropic hormone
Melanocyte stimulating hormone releasing hormone (MRH) stimulating	stimulates the release of melanocyte hormone
Melanocyte stimulating hormone inhibiting hormone (MIH)	inhibits the release of melanocyte stimulating hormone

Table 11.2 : Hormones of Pituitary Gland and their Action on Target Organs

Part of Pituitary	Principal Cell Type	Hormones	Principal Actions	Target Organs
Adeno-hypophysis	Somatotroph	Human growth hormone (hGH)	Growth of body cells specially of bones of limbs, stimulates protein synthesis and inhibits protein breakdown; hydrolysis of fats, retards use of blood glucose for ATP production	General
	Thyrotroph	Thyroid stimulating hormone (TSH)	Controls secretion of thyroid hormones	Thyroid gland
	Corticotroph	Adrenocorticotropic hormone (ACTH)	Controls secretion of adrenal cortex hormones	Adrenal cortex
		Melanocyte stimulating hormone (MSH)	Stimulates cutaneous pigmentation by dispersion of melanin granules	Melanocytes in skin
	Lactotroph	Prolactin (PRL)	Stimulates milk production and secretion, participates in control of reproduction, osmoregulation, growth and metabolisim	Mammary glands
	Gonadotroph	Follicle stimulating hormone (FSH)	In males, stimulates spermatogenesis. In females, growth of ovarian follicles	Gonads

		Interstitial cell stimulating hormone (ICSH)	In males, secretion of testosterone	Gonads
		Luteinising hormone (LH)	In females, together with FSH, it triggers ovulation, stimulates conversion of ovarian follicles into corpus luteum	Gonads
Neuro-hypophysis	No hormones synthesised here. Its hormones are synthesised in hypothalamus	Oxytocin (OT)	Stimulates contraction of uterine muscles during birth; initiates ejection of milk	Mammary glands
		Antidiuretic hormone (ADH) or vasopressin	Stimulates reabsorption of water and reduction of urine secretion; stimulates constriction of blood vessels and thus increases blood pressure	Kidneys

The osmoreceptors in the hypothalamus detect the resulting increase in blood solute concentration. This triggers the release of ADH. As a result, water passes out of the descending loop in the nephron of kidney into the surrounding tissue. Following drinking, with uptake of water, there is decrease in the osmolarity of the blood. This lessens the secretion of ADH by feedback inhibition loop. Although oxytocin has a similar structure to vasopressin, it has distinctively different physiological functions, mediated via specific oxytocin receptors on target cells. It is present in both sexes, but its effects are well understood only in females. Oxytocin stimulates the rhythmic contractions of uterine smooth muscle during parturition (child birth). It also stimulates milk ejection from lactating breast, in response to infant suckling by contracting myoepithelial cells present in the alveolar secretory epithelium. Even sight and sound of the baby can cause a nursing mother to secrete this hormone.

Thyroid Gland and its Hormones

Thyroid is butterfly-shaped gland that straddles on either side of upper part of trachea below larynx (Fig. 11.3). The right and left lateral lobes lie on either side. Connecting the lobes is a mass of tissue, called **isthmus**. The thyroid gland consists of microscopic spherical sacs, called **thyroid follicles**. These contain colloid, composed of the glycoprotein thyroglobulin, which fill most of the thyroid gland. The wall of each follicle consists of two types of cells. Under the

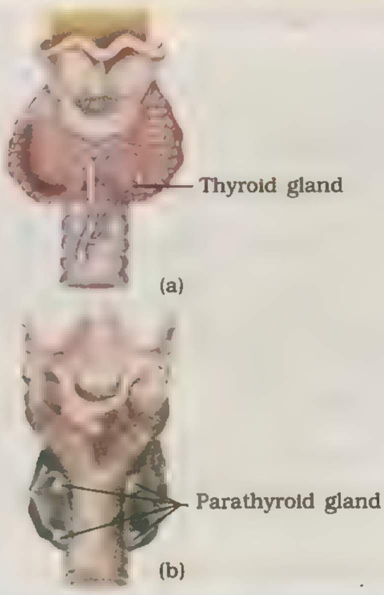


Fig. 11.3 *(a) Thyroid gland (b) Parathyroid gland*

influence of TSH, the follicular cells synthesise **thyroxine**, which is also called T_4 because it contains four atoms of iodine, and **triiodothyronine** or T_3, which contains three atoms of iodine. T_3 is more active and several times more potent than T_4, but it is secreted in smaller amounts. T_4 is converted to T_3 by removal of one iodine. Because T_4 and T_3 have virtually identical effects on the target cells, they are usually considered together under the designation **thyroid hormone** or TH. The thyroid gland is the only endocrine gland that stores its secretary product in large quantity. T_3 and T_4 are synthesised by attaching iodine to the amino acid tyrosine by enzymatic action, stored for some period of time and then secreted into the blood. The other parafolicular cells produce **calcitonin**, which influences calcium homeostasis. The functions of this vital gland are :

(i) to regulate metabolic rate;

(ii) to regulate metabolism by stimulating protein synthesis;

(iii) to maintain normal body temperature;

(iv) to help in the metamorphosis in a frog;

(v) to regulate the development of mental faculties; and

(vi) to enhance some actions of neurotransmitters : adrenaline and non-adrenaline.

(vii) to control blood-bone Ca^{2+} level.

Table 11.3 summarises the disorders resulting from the malfunctioning of the thyroid gland.

Parathyroid and its Hormones

The parathyroid glands in humans are two pairs pea-sized organs (Fig. 11.3), clinging like limpet to the posterior or dorsal surface of thyroid. But they are totally independent of the thyroid, both developmentally and functionally.

The parathyroid hormone (PTH) is vital to regulate the calcium and phosphate balance between the blood and other tissues. PTH inhibits collagen synthesis by osteoblasts and bone resorption by osteoclasts. Calcium itself controls the secretion of PTH by feedback mechanism. PTH mobilises the release of calcium into the blood from the bones.

It aids its dietary absorption from the intestines and reabsorption from kidneys.

Table 11.3 : Disorders Resulting from Malfunctioning of Thyroid Gland

Hypothyroidism	Hyperthyroidism
It can result from (i) primary failure of thyroid gland itself (ii) secondary to hyposecretion of TRH, TSH or both; or (iii) an inadequate dietary supply of iodine. The symptoms include reduction in overall metabolic activity and poor tolerance of cold. **Cretinism (in children)** It exhibits dwarfism because the skeleton fails to grow and mature. Patients are severely mentally retarded as the brain fails to develop fully. Other clinical features include dry skin, thick tongue, prolonged neonatal jaundice, lethargy, respiratory problems and constipation. **Myxoedema (in adults)** The cardinal symptom of this disorder is edema (accumulation of interstitial fluid) that causes the facial tissues to swell and look fluffy.	**Grave's disease (= exophthalmic goiter)** It is an autoimmune disorder in which the person produces antibodies that mimic the action of TSH, but are not regulated by normal negative feedback controls. These patients have a peculiar edema behind the eyes called exophthalmos, which causes the eyes to protrude. This disorder, like myxoedema, also occurs more often in females.

Table 11.4 : Disorders Resulting from Malfunctioning of Parathyroid Gland

Hypoparathyroidism	Hyperparathyroidism
Accidental damage to the parathyroids or their blood supply during thyroidectomy surgery, causes **hyposecretion** of PTH.	A tumour usually in the parathyroids causes **hypersecretion** of PTH.
Because of deficiency of Ca^{2+} , neurons become depolarised without the usual stimulus. Consequently, nerve and muscle action potentials arise spontaneously, leading to muscle twitches, spasms and convulsions. This condition is called **hypocalcaemic tetany**.	Because of demineralisation, the bones become deformed and easily fractured. If untreated, this condition may lead to **osteitis fibrosa cystica**, so named because the areas of the destroyed bone tissue are replaced by cavities that are filled with fibrous tissues.

The problems of malfunctioning of parathyroid gland are summarised in Table 11.4.

Adrenal Glands and their Hormones : A pair of adrenal (suprarenal) glands are located, one on each side of the spinal column, just superior to each kidney (Fig. 11.4).

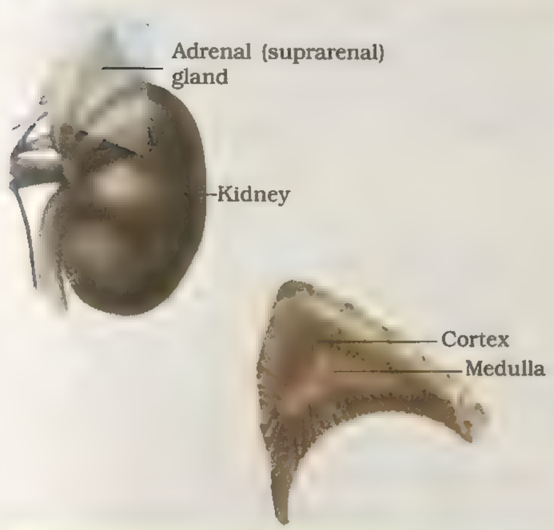


Fig. 11.4 *Adrenal gland*

Shaped like a tricorn hat, each gland is a double gland consisting of an outer cortex and an inner medulla.

The adrenal cortex produces steroid hormones through the modifications of cholesterol, many of which differ from each other by only one or two atoms. Despite these apparently minor differences, the various hormones have strinkingly different functions. They bind to different receptors in target cells, and affect sets of chemical reactions. **Cortical steroids** (corticoids) can be grouped into three functional categories (Table 11.5).

(a) *Mineralocorticoids* : They regulate salt-water balance through their effect on kidney, blood volume and blood pressure. About 95 per cent of the mineralocorticoid activity is due to aldosterone.

(b) *Glucocorticoids* : They regulate carbohydrate, protein and lipid metabolism, in a manner nearly opposite to that of insulin. They influence a wide variety of other vital functions, including inflammatory reactions and the capacity to cope with stress.

(c) *Gonadocorticoids* : Sex hormones of the adrenals are very similar, both chemically and functionally to the sex hormones produced by the gonads.

The medulla secretes two catecholamine hormones. **Adrenaline** (also known as epinephrine) reinforces the role of sympathetic nervous system. The other product of the adrenal medulla, **noradrenaline** (norepinephrine) is closely allied to adrenaline chemically and exerts similar effects. For example, adrenaline prepares us ready

Table 11.5 : Hormones of Adrenal Glands and their Action on the Target Cells

Adrenal Gland Hormones	Principal Action	Target Tissue
Mineralocorticoids : aldosterone (mainly) deoxycorticosterone	control electrolyte and water metabolism; increase blood levels of Na^+ and water; decrease blood levels of K^+ by stimulating kidney tubules to reabsorb more Na^+, Cl^- and water and less K^+	Kidney
Glucocorticoids : cortisol (mainly) corticosterone cortisone	raise blood glucose level; promote liver glycogen formation; breakdown of plasma protein; increase availability of amino acids for enzyme synthesis; general resistance to long-term stress by inflammatory and allergic responses	Liver
Gonadocorticoids : androgens estrogens	development of secondary sexual characteristics, particularly those of the male; concentrations secreted by adults are so low that their effects are usually insignificant	Gonads
Adrenaline	stimulates elevation of blood glucose by converting liver glycogen to glucose; rise in blood pressure; acceleration of rate and force of heartbeat; constriction of skin and visceral smooth muscle capillaries; dilation of arterioles of heart and skeletal muscles; increase in breakdown of lipids; increase in oxygen consumption; erection of hairs; dilation of pupils; initiates stress responses	Skeletal muscles, cardiac muscles, smooth muscles, blood vessel, fat cells
Noradrenaline	stimulates reactions similar to those produced by adrenaline	

instantly for action whenever there is a stress or emergency situation. It also activates hypothalamus and, in turn, triggers pituitary gland. The pituitary flashes alarming signal by secreting a hormone, known as **adrenocorticotropic hormone**, which finds its way through the blood stream to the adrenal glands, because in anger or fear they produce even more medullary hormones : adrenaline or noradrenaline.

A third hormone, called **cortisol**, also prepares your body for after-effects of danger. It controls the pumping action of heart. It unlocks energy from fat, mobilises amino acids to repair the damaged cells. It also helps in reducing pain. This is why people may not feel any pain from a severe injury until long after because cortisol is mimicked by corticosteroid drugs, which have a range of uses, from asthma to arthritis.

Pancreas and its Hormones

It is about 15 cm long and weighing about 85 g, lying next to the duodenum. But, it is both an exocrine and an endocrine gland. Exocrine cells of pancreas secrete about 1 litre of pancreatic juice a day, containing at least three enzymes to aid the digestive processes. Endocrine cells of pancreas form groups of cells, called **islets of Langerhans** located around capillaries within the lobules (Fig. 11.5). About a million islets of Langerhans, each with approximately 3,000 cells, comprise about 1.5 per cent of the pancreatic mass. There are three types of hormone-secreting cells. The α cells secrete the

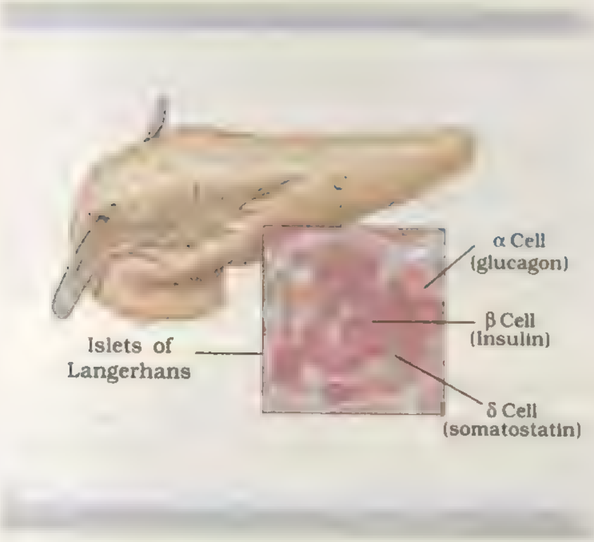


Fig. 11.5 *Pancreas showing its internal structure*

hormone **glucagon**; the β cells secrete **insulin**, and the δ cells secrete **somatostatin** (Table 11.6). These hormones regulate the level of glucose in the blood. When the blood glucose level becomes excessive, insulin acts on the three target tissues : liver, muscle and adipose cells. Insulin causes (indirectly) the liver to take up glucose and convert it into glycogen and fat. It facilitates the uptake of glucose in the muscle and adipose cells causing the levels of glucose in the blood lowered or normalised. Somatostatin acts as a paracrine to inhibit the secretion of glucagon and insulin. Table 11.7 summarises the disorders resulting from insulin deficiency and excesses.

Table 11.6 : Hormones of Pancreas and their actions on Target Cells

Endocrine Cells of Pancreas	Hormone	Principal Action	Target Tissue
α cells	Glucagon (polypeptide)	raises blood glucose level by i) accelerating breakdown of glycogen into glucose in liver; ii) promoting conversion of other nutrients, such as amino acids and lactic acid, into glucose in liver; iii) enhancing release of glucose into blood	Liver, adipose tissue
β cells	Insulin (polypeptide)	lowers blood glucose level by i) stimulating transport of glucose from blood to muscle and adipose cells, and indirectly causing the liver to take up glucose; ii) promoting both oxidation of glucose and conversion of glucose into glycogen in muscles as well as liver cells; iii) inhibiting metabolic breakdown of stored glycogen in liver and muscle cells; iv) promoting synthesis of fats from glucose by adipose tissue and also inhibiting metabolic breakdown of fat; v) promoting uptake of amino acids by liver and muscle cells, and stimulating protein synthesis while inhibiting protein breakdown	Liver, muscle, adipose tissue
δ cells	Somatostatin (polypeptide)	inhibits secretion of glucagon and insulin; decreases secretion, motility and absorption in the digestive tract	Pancreas

Table 11.7 : Disorders Resulting from Insulin Deficiency and Excess

Hyperglycaemia	Hypoglycaemia
It results from **hyposecretion** of insulin. Symptoms include : high blood glucose level; breakdown of muscle tissue; loss of weight; tiredness.	It results from **hypersecretion** of insulin. Symptoms include : low blood glucose level; hunger; sweating; Irritability; double vision.

Diabetes mellitus is a group of disorders that lead to an increase in the level of glucose in the blood (hyperglycaemia). This is due to underactivity of β cells in islets of Langerhans, that results in reduced secretion of insulin. Such a condition is called **insulin-dependent diabetes**. Table 11.8 compares the cause and symptoms of diabetes mellitus and diabetes insipidus.

Gastrointestinal Hormones

Gastrointestinal (GI) hormones are secreted into the blood by specialised cells lining the gastrointestinal tract, whose aggregate mass is greater than that of the rest of the endocrine system. You have studied about the major GI hormones in Chapter 5.

Pineal Gland and its Hormones

The endocrine gland attached to the roof of third ventricle in the rear portion of brain, is known as the pineal gland, named for its resemblance to a pine cone. It has no direct connection with central nervous system. It is variable in size and weighs about 150 mg, but it is richly vascularised and secretes several hormones, including melatonin. In humans, it has no light-sensitive cells, like lower vertebrates, where pineal is eye-like and responds to light. Pineal gland functions as a biological clock and a neurosecretory transducer, converting neural information. More melatonin is produced during darkness. Its formation is interrupted when light enters the eyes and stimulates the retinal neurons. They transmit impulses to the hypothalamus, and finally to the pineal gland. The result is inhibition of melatonin secretion. In this way, the release of melatonin is governed by the diurnal dark-light cycle.

Thymus

Because of its role in immunity, the details of structure and function of thymus gland will be discussed in Chapter 25. It is also called "the throne of immunity", or training school of T-lymphocytes. Hormones produced by the thymus gland is called **thymosin**. Thymosin released in the bloodstream has a stimulating effect on the entire immune system. It promotes proliferation and maturation of T-lymphocytes. If you got severe dose of radiation, enough to knock out your immune system, your thymosin might be life-saver, stimulating the spleen and other

Table 11.8 : Comparison of Diabetes Mellitus and Diabetes Insipidus

Diabetes Mellitus	Diabetes Insipidus
It results from hyposecretion of **insulin**. Symptoms include : excessive and frequent urination excessive thirst; excessive eating	It results from hyposecretion of **antidiuretic hormone**. Symptoms include : excretion of large amounts of urine; thirst; dehydration

organs that had shut down to get back into production. Thymosin production decreases with advancing age and entirely ceases by about 50 years.

Sex Organs and their Hormones

Testes in males and ovaries in females secrete sex hormones at puberty. You will learn in detail about the hormonal control of human reproduction in Chapter 14. Table 11.9 shows the reproduction hormones and their functions.

Table 11.9 : Hormones Regulating Reproduction

Endocrine Gland	Hormones	Principal Action
Ovarian follicle	Estrogen	stimulates development and maintenance of female sexual characteristics like high pitch, female voice and female pattern of body hair distribution at puberty; together with gonadotropic hormones of the anterior pituitary gland, they also regulate the menstrual cycle.
Corpus luteum	Progesterone and Estrogen	stimulate uterine lining for embryo implantation to maintain pregnancy (foetal development); prepare the mammary glands for lactations and regulate oogenesis, progesterone inhibits ovulation.
	Relaxin	relaxes pubic symphysis and helps dilate uterine cervix near the end of pregnancy.
	Inhibin/activin	inhibition/activation of FSH and GnRH production.
Testes	Testosterone	stimulates the descent of testes and male pattern of development (before birth); stimulates development and maintenance of male sexual characteristics and expression of secondary characteristics, such as beards, moustache and low-pitch voice; starting at puberty; stimulation of spermatogenesis; growth spurt.
	Inhibin/activin	inhibition/activation of LH and FSH production.
Placenta	Human Chronic Gonadotropin	stimulates progesterone release from the corpus luteum and maintains it.
	Human placental lactogen	stimulates mammary growth.

Hypogonadism : Defects in, or injury to, the hypothalamus, the pituitary, or the testes or ovary, result in hypogonadism. Male hypogonadism can consist of deficient androgen production (hypofunction of Leydig cell), deficient sperm formation (hypofunction of Sertoli cell), or both, before puberty.

It results in the lack of development of secondary sexual characteristics and male musculature. Female hypogonadism results from hyposecretion of estrogen, resulting in cessation of reproductive cycles. Such hypogonadism can result from a shortage of pituitary gonadotropins (LH, FSH, or both) or can represent primary testicular/ovary failure.

Precocious puberty : True sexual precocity, i.e., early maturation of ovaries and testes with production of ova before the age of 9 years in girls, or sperm before 10 years in boys, occurs without evident cause. Sexual pseudoprecocity results from excesses of sex hormones from the adrenal cortex, testis, ovary or from other sources, including extragonadal tumours. Sexual

pseudoprecocity in boys occurs as a consequence of excess of testosterone produced by tumours of the testis or adrenals. In such cases, enlargement of the penis, accelerated appearance of sexual characteristics, such as, pubic and axillary hair, masculinisation, faster body growth, and ultimate stunting are present. Sexual pseudoprecocity in girls arises from increased supply of estrogen secreted by tumours of the ovaries or adrenals. The external manifestations of sexual maturation, for example, breast formation and appearance of pubic hair, appear early, but the maturation and discharge of ova do not occur.

Eunuchoidism : This results from the failure of testosterone secretion. For this disorder, secondary sex organs, such as prostate gland, seminal vesicles and penis, remain infantile and small in size and fail to function. Spermatozoa fail to be produced. External sex characters like beards, moustaches and low-pitch male voice fail to develop.

Gynaecomastia : It is the development of breast tissue in males, and is usually due to perturbation of estrogen to androgen ratio. In the neonatal period and during puberty, gynaecomastia is due to temporary increase in circulating estrogen. Decreased testosterone in later life may also lead to gynaecomastia.

11.2 Molecular Mechanism of Hormone Action

How does the neuroendocrine control work ? The hormones are released in very small quantities, yet they can cause widespread responses in cells or tissues all over the body. These responses can be quite specific and selective in different cells. All vertebrate hormones belong to one of four chemical groups. Some hormones, such as adrenaline and thyroid hormone, are small molecules derived from the amino acid tyrosine, others, such as vasopressin and oxytocin, are short peptides, still other hormones, like insulin and glucagons, are longer polypeptide chains. Testcsterone and estrogen are steroid hormones. Catecholamines, peptide and protein hormones are not lipid-soluble, and so, cannot enter their target cells through the bilipid layer of plasma membrane. Instead, these water-soluble hormones interact with a surface receptor, usually a glycoprotein, and thus, initiate a chain of events within it. The hormone insulin provides a well-studied example of how this happens.

Extracellular Receptor

The membrane bound receptors of insulin is a heterotetrameric protein consisting of four subunits, two α-subunits protrude out from surface of the cell and bind insulin, and two β-subunits that span the membrane and protrude into the cytoplasm (Fig. 11.6 a). Such receptors range from fewer than 100 in most cells in our body to more than 1,00,000 in some liver cells.

Let us now consider various mechanisms whereby hormones (first messenger) induce their actions at the cellular and molecular levels.

(i) Binding to the receptor : Binding of insulin to the outer subunits of the receptor causes a conformational change in the membrane spanning β-subunits, which is also an enzyme, a tyrosine kinase (Fig. 11.6b). The activated β-subunits add phosphate groups of specific tyrosine residues located in cytoplasmic domain of the receptor, as well as a variety of insulin receptor substrates.

(ii) Second messengers – the mediator : As a result of hormone binding response, a transducer **G-protein** activates enzyme **phosphodiesterase**. This enzyme makes **phosphatidylinositol 4,5-biphosphate** (PIP_2) into a pair of mediators, examples of second messengers : **inositoltriphosphate** (IP_3) and **diacylglycerol** (DG). In turn, IP_3, which is water-soluble, and so diffuses into cytoplasm and triggers the release of another messenger Ca^{2+} ions from intracellular endoplasmic reticulum activating many calcium-mediated processes. While DG remains in the membrane where it activates an enzyme called **protein kinase C**, which in turn, activates many other enzymes, such as pyruvate dehydrogenase, and so brings about the physiological effects.

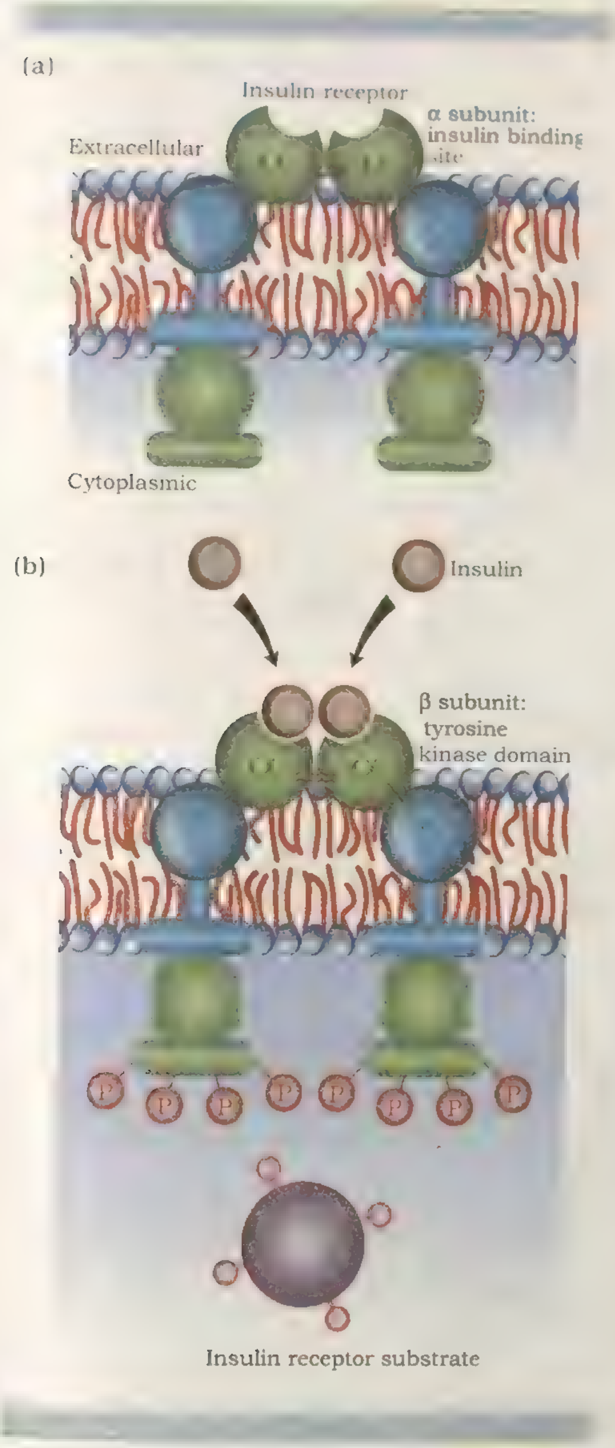


Fig. 11.6 (a) *Membrane bound insulin receptor* (b) *Binding of insulin to α-subunit of its receptor ; the activated β-subunit add phosphate groups of specific tyrosine residues located in cytoplasmic domain of the receptor as well as a variety of insulin receptor substrates.*

A variety of hormones use another second messenger, the **cyclic form of adenosine monophosphate**, (cAMP). The enzyme **adenylate cyclase** converts adenosine triphosphate (ATP) into cAMP.

(iii) Amplification of signal : Mediators amplify the signal in an expanding cascade of response. A single glucogon receptor, for example, activates many molecules of DG, and each protein kinase C molecule activated by DG will, in turn, activate many other enzyme molecules. DG and IP_3 are, intermediary compounds that amplify a hormonal signal and so set into action a variety of events within the affected cell. Because an enzyme can be used over and over again, a single molecule of active adenylate cyclase can catalyse production of about 100 molecules of cAMP. In muscle or liver cells, when hormones, such as, adrenaline bind receptors, the receptors change shape and bind to G protein, causing it, in turn, to bind the nucleotide **guanosine triphosphate** (GTP) and activate another protein adenylate cyclase. The result of this complex cascade of interactions is the production of large amounts of cAMP (Fig. 11.7). cAMP activates the enzyme **protein kinase A**, which, in turn, activates the enzyme phosphorylase kinase. Each molecule of protein kinase A activates roughly 100 molecules of enzyme, phosphorylase kinase and so on. The net result is that a single molecule of adrenaline may lead to release of as many as 100 million molecules of glucose within only 1 or 2 minutes. No wonder only very small quantities of hormone are needed.

(iv) Antagonistic effect : Many cells use more than one second messenger. In heart cells, cAMP serves as a second messenger, speeding up muscle cell contraction in response to adrenaline, while **cyclic guanosine monophosphate** (cGMP) serves as another second messenger, slowing muscle contraction in response to acetylcholine. It is in this way that the sympathetic and parasympathetic nervous systems achieve antagonistic effect on heartbeat. Another example of antagonistic effect is insulin, which lowers blood sugar level, and glucagon, which raises it.

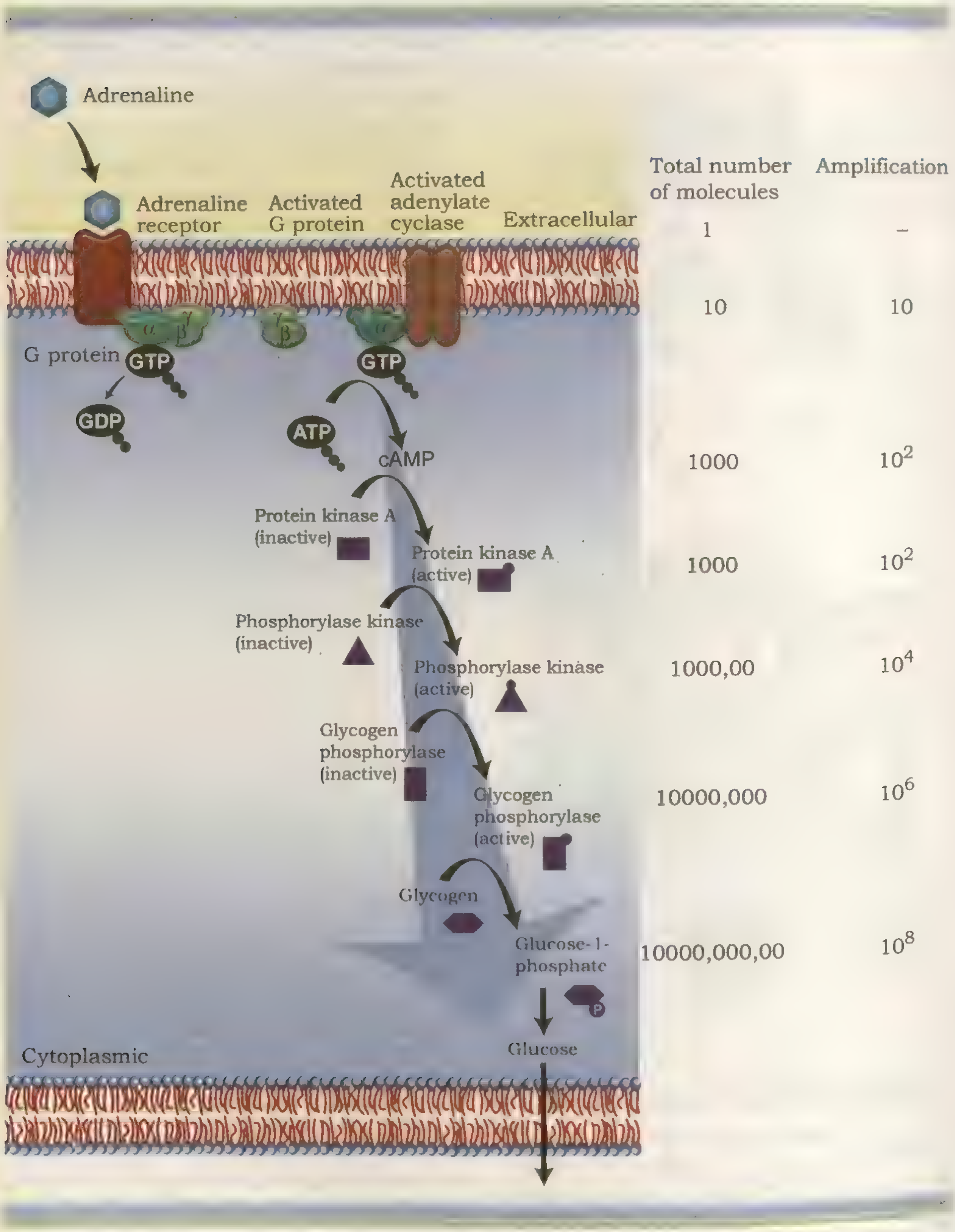


Fig. 11.7 *Mode of hormone action through the extracellular receptor and its amplification*

(v) Synergistic effect : Another type of hormonal interaction is known as synergistic effect. Here, two or more hormones complement each other's actions and both are needed for full expression of the hormone effects. For example, the production, secretion and ejection of milk by mammary glands require the synergistic effects of estrogens, progesterone, prolactin and oxytocin.

Intracellular Receptors

We have discussed many dramatic effects of hormone, for instance, testosterone. Yet, its concentration in the plasma of adult human male is only 30 to 100 ng per ml. How can hormones in such tiny quantities have such widespread and selective actions? Unlike catecholamine and peptide hormones, steroid and thyroid hormones are lipid-soluble hormones and readily pass through the plasma membrane of a target cell into the cytoplasm. There they bind to specific **intracellular receptor proteins**, forming a complex that enters the nucleus and bind to specific regulatory sites on chromosomes. The binding alters the pattern of gene expression, initiating the transcription of some genes (DNA), while repressing the transcription of others. This results in the production of specific mRNA translation products, proteins and usually enzymes. The actions of lipid-soluble hormones are slower and last longer than the actions of water-soluble hormones. These cause physiological responses that are characteristic of the steroid hormones.

SUMMARY

Endocrine glands secrete most of the circulating hormones in the blood stream. Because the activity of these messenger molecules is under the direct control of the nervous system, these hormones constitute a chemical extension of the nervous system. Hormones are chemically peptides or catecholamines or steroids molecules. They have a central role in the economy of the body because they influence multiple functions and are essential for growth, reproduction and homeostasis.

The brain maintains long-term control over physiological processes by synthesising releasing hormones in the hypothalamus. Some neurosecretory cells in the hypothalamus synthesise two hormones (vasopressin and oxytocin), which are released into the blood from their axon terminals in the posterior pituitary, a distinct gland itself. The anterior lobe of the pituitary, another distinct gland, is connected to the hypothalamus by portal vein. It secretes seven principal kinds of hormones, each corresponding to a specific releasing hormone from the hypothalamus.

Thyroid hormones regulate basal metabolic rate and, thus, activity and growth as well as some aspects of protein synthesis. Calcitonin regulates blood calcium level. Parathyroid hormone regulates the balance between calcium and phosphate in body fluids, which affects calcium deposition in bones.

The islet cells of the pancreas secrete insulin, which stimulates uptake and use of glucose. They also secrete glucagon, which has the opposite effect. Diabetes results from immunological destruction of the islet cells, reduced insulin secretion, or loss of sensitivity to insulin.

The medulla of adrenal glands secretes adrenaline and noradrenaline, which prepare the body for high activity. The cortex produces a variety of cholesterol-based hormones that regulate metabolism (glucocorticoids) and body fluids (mineralocorticoids), and also act as sex hormones.

Thymosin secreted by thymus stimulates maturation of immune system cells. Melatonin controls skin colour in some animals, and appears to control annual reproductive cycles.

Some hormones, such as steroid hormones, act by binding to DNA and altering gene expression.

Other hormones bind to membrane receptors, where they either open ion channels (usually Ca^{2+}) or trigger production of other chemical messengers inside the cell. Typically the receptor activates an enzyme via a G-protein intermediate, which generates cAMP, which in turn, activates the first step in an enzyme cascade.

Cellular reactions are faster, and more accurate, when activity is determined by ratios of two antagonistic hormones, rather than by absolute levels of a single hormone.

EXERCISES

1. Answer true or false to the following :
   (a) Endocrine control is integrated with neural control at the level of the hypothalamus.
   (b) Thyroid hormone is required for normal perinatal brain development.
   (c) Glucocorticoids are anabolic steroids.
   (d) Adrenal medulla releases adrenaline and noradrenaline in a ratio of approximately 10:1.
   (e) Testosterone is water soluble and acts via receptors on the plasma membrane of the target cells.
   (f) Hypoglycemia occurs most commonly in diabetic patients.
   (g) Oxytocin is released in response to mechanical stimulation of the breast nipple.
2. Choose the correct option from among those provided:
   The posterior pituitary
   (a) produces oxytocin.
   (b) is under the control of hypothalamic releasing neurohormone.
   (c) secretes trophic hormones.
   (d) secretes neurohormone.
3. Parathyroid hormone :
   (a) is produced by the thyroid gland.
   (b) is released when blood calcium levels fall.
   (c) stimulates osteoblasts to lay down new bone.
   (d) stimulates calcitonin release.
4. Steroid hormones :
   (a) have only cell surface receptors.
   (b) are lipophobic.
   (c) act through altering the activity of proteins in the target cell.
   (d) are produced by the adrenal cortex.

5. Both adrenaline and cortisol are secreted in response to stress. Which of the following statement is also true for both of these hormones?
   (a) They act to increase blood glucose.
   (b) They are secreted by the adrenal cortex.
   (c) Their secretion is stimulated by adrenocorticotropin.
   (d) They are secreted into the blood within seconds of the onset of stress.

6. Match the definitions of column I with appropriate terms from column II.

Column I	Column II
(i) product of an endocrine gland	(a) aldosterone
(ii) lipid-soluble hormones	(b) pineal gland
(iii) effect is to conserve sodium ion and water	(c) insulin
(iv) lowers blood glucose levels	(d) hormone
(v) source of melatonin	(e) adrenaline
(vi) secreted by the adrenal cortex	(f) steroid
(vii) secreted by the adrenal medulla	(g) parathyroid hormone
(viii) maintains Ca^{2+} level in the plasma	(h) oxytocin
(ix) stimulates secretion of milk	(i) prolactin

7. Distinguish between :
   (a) follicle stimulating hormone and lutenising hormone
   (b) vasopressin and oxytocin
   (c) estrogen and progesterone
   (d) glucocorticoids and mineralocorticoids
   (e) diabetes mellitus and diabetes insipidus
   (f) exophthalmic goitre and iodine deficiency goitre
   (g) cretinism and dwarfism.

8. Discuss the role of hypothalamus and pituitary as a coordinated unit in maintaining physiological processes.

9. Why is the endocrine system considered a chemical extension of the nervous system?

10. What are the seven principal hormones produced by the anterior pituitary? What function does each serve?

11. What hormones are secreted by the posterior pituitary gland? What function does each serve? Where are these hormones actually produced? How are these hormones transported to the region from which they are released?

12. What are the examples of pairs of antagonistic hormones associated with basal metabolism? How does each pair function?

13. What two hormones are produced by the adrenal medulla? What non-hormonal functions do they serve?

14. From what chemical compounds are all steroid hormones derived? Mention two examples of steroid hormones.

15. In general, how do steroid hormones effect changes in their target cells?

16. What hormones are produced when the body's blood glucose levels drop below normal? How do these hormones act to return the level to normal? What hormone is produced when the body's blood glucose levels become elevated? How does this hormone act to return the level to normal?

17. What is diabetes? What is the ultimate hormonal deficiency in these diseases? How does this affect an individual's ability to use glucose? What are some possible treatments for diabetes mellitus?

18. Why do you suppose the brain goes to the trouble of synthesising releasing hormones, rather than simply directing the production of the pituitary hormones immediately?

19. Which endocrine glands are controlled by the secretion of other endocrine glands?

20. How is communication among the parts of an organism accomplished?

UNIT EIGHT

REPRODUCTION, GROWTH AND DEVELOPMENT

One of the fundamental tenets in biology is that all life comes only from pre-existing life. To beget its kind is an essential trait of life. Individuals are born and they die, but organisms rise above time by reproducing offspring. Reproduction is a marvellous culmination of individual transcendence. It is the only method for compensation of the loss of life due to death. Reproduction also makes the perpetuation of life easy. However, reproduction is not restricted to the organismic level only. Organic molecules, such as nucleic acids, are observed to produce their replica by a method called replication. All cells can divide to produce new generation of cells. Plants and animals reproduce by employing a wide range of mechanisms. But the basic types are asexual and sexual. Sexual reproduction requires the formation of gametes, which fuse to form zygote and the zygote passes through embryonic development to form a young individual. Development is the emergence of a multicellular organism from a single group of cells. It involves growth, differentiation and morphogenesis. Growth is characterised by cell proliferation, or secretion of extracellular materials. Differentiation means diversification of cell to attain their specific functions. Morphogenesis is the emergence of new pattern in the embryo. However, development is also observed in the post-embryonic life. The present unit will deal with different mechanisms of reproduction in flowering plants and animals, in general. Also the process of embryonic development of humans and post-embryonic development in relation to growth in plants and animals, and regeneration in animals will be discussed. Finally, the relation between growth and ageing will be analysed.

Panchanan Maheshwari

(1904-1966)

Born in November 1904 in Jaipur (Rajasthan), Panchanan Maheshwari got solace in books and magazines in his school days and later developed interest in scientific magazines. During his college days, he was inspired by Dr. W. Dudgeon, American missionary teacher, to develop interest in Botany and especially morphology. His teacher once expressed that if his student progresses ahead of him, it will give him a great satisfaction. These words encouraged Panchanan to enquire what he could do for his teacher in return. Dudgeon replied that "do for your students what I have done for you." Meticulously following his teacher's advice, he did train a host of talented students. He pursued his postgraduate university education in botany at Allahabad University.

He worked on embryological aspects, especially the embryo sac of several plants belonging to more than 100 families. He popularised the use of embryological characters in taxonomy. He established the Department of Botany, University of Delhi as an important centre of research in embryology and tissue cultured. The department was recognised by the University Grants Commission as a centre of Advance Study in Botany. Panchanan Maheshwari was assisted by his wife in preparation of slides in addition to her household duties. Way back in 1950 he talked of contacts between embryology, physiology and genetics. He also emphasised the need of initiation of work on artificial culture of immature embryos. These days, tissue culture has become a landmark in science. His work on test tube fertilisation and intra-ovarian pollination won worldwide acclaim. The book considered "magnum opus", the *Introduction to the Embryology of Angiosperms* was completed by him in 1950. He also founded an International research Journal 'Phytomorphology' and popular magazine The 'Botanica' in 1950. Volume on *Recent Advances in Embryology of Angiosperms* (1963), edited by Maheshwari, became a referral for the researchers in embryology.

He devoted his life to science. Many of his wellwishers and students felt pride in naming their new finds after him, such as *Panchanania jaipurensis* (fungus), *Oldenlandia maheshwarii* (Rubiaceae member).

He was honoured with fellowship of Royal Society of London (FRS), Indian National Science Academy and several other institutions of excellence. His interest in science also made a significant contribution to school education in the form of textbooks of Biology for secondary schools published by NCERT, in 1964.

Chapter 12

Reproduction in Flowering Plants

Reproduction is one of the most important characteristics of all living beings, both plants and animals. It is a process of producing offspring and a means of self-perpetuation. The modes of reproduction vary according to individual species and available conditions. In lower organisms, it may be simply by division of cell or budding; whereas in higher organisms, it may be with the help of fully developed sex organs. In higher plants, reproduction is either without the involvement of sex organs or fusion of gametes (asexual), or with the involvement of sex organs - stamen and pistil (sexual). In some cases, special modes of reproduction, namely parthenogenesis, sporophytic budding and polyembryony, are also reported. In this chapter, you will study various processes involved in the reproduction of flowering plants.

12.1 Modes of Reproduction

In flowering plants, there are several modes of reproduction, which can be broadly arranged into asexual or vegetative, and sexual types.

In vegetative reproduction, the offspring are produced from the somatic cells; whereas in sexual reproduction, there is the fusion of male and female gametes (germ cells). In the case of vegetative reproduction, the somatic cells may be from root, stem, leaf, or even buds of leaf and flower. In sexual reproduction, the gametes from male and female organs of the flower are fused to produce a zygote.

In some plants, special modes of propagation, namely parthenogenesis, sporophytic budding, polyembryony and apomixis occur. The production of synthetic (artificial) seeds has also been possible through tissue culture.

12.2 Vegetative Reproduction

The regeneration of plants from a portion of the vegetative part is quite common and diverse. The organs like root, stem, leaf and even buds, are variously modified to help the plant in vegetative propagation. For the propagation of economically useful plants, several techniques have been developed by humans. These are cutting, grafting and layering, and are generally referred to as artificial methods of vegetative propagation. Nowadays many plants are also multiplied through tissue culture technique. The resulting offspring are normally identical, and resemble the parent forms in almost all respects. Therefore, gardeners often use these methods for getting plants of same types. The methods of vegetative propagation are grouped into natural and artificial.

Natural Methods

In natural methods of propagation, a portion of the plant gets detached from the body of the mother plant. This detached portion may be a part of stem, leaf, root or even flower, which develops into a new independent plant under suitable environmental conditions.

You have studied about the morphology of root, stem and leaf, and their modifications in Class XI. You know that modifications of these parts are meant to perform some special functions and to overcome unfavourable conditions. The underground modifications of stem, like rhizome, tuber, bulb and corm, are used for vegetative propagation of plants in the field. Ginger, potato, onion and zamikand are grown with the help of underground stem. The stem of

plants with subaerial modifications, as in *Pistia*, *Chrysanthemum*, *Eichhornia*, pineapple and banana, are also used for propagating plants. The plants of sweet potato, asparagus, tapioca, and dahlia are propagated through roots. *Bryophyllum* and *Kalanchoe* are commonly propagated through leaves (Fig. 12.1). The buds, produced in their notches along the leaf margin, fall on to the soil and develop into new plants.

In plants, like *Agave*, wild yam and *Oxalis*, small buds develop near the flower, leaf axil and tuberous root, respectively, to give rise to new plants.

Artificial Methods

Some flowering plants have a capacity to develop a part of their somatic body into a new independent plant. This is done by applying special techniques. Many plants like rose, sugarcane, croton, tapioca, china-rose can easily be grown from **stem cuttings,** by putting them into the moist soil. Sometimes, the **root cuttings** from lemon, tamarind, etc. sprout, producing roots and shoots, if they are put in the moist soil. **Layering** is one of the most common methods used for propagating plants like rose, jasmine, grape vine and lemon. Layering can be done by bending down the lower branch close to the ground and covering it with moist soil. The covered portion of the branch produces roots after some days and can be cut and grown independently.

Grafting is practised in plants which do not root easily, or have a weak root system. It is an art of joining parts of two plants of the same or allied species in such a way as to bring about an organic union or fusion of the tissues. It is successful in plants which have cambium for secondary growth. The basic or main part is called **stock**, and the portion to be grafted on to the stock is called a **scion**, which is generally taken from the plant having superior characters. It is practised in mango, apple, pear, citrus, guava and rubber plant. Grafting may be of different types, namely bud grafting, approach grafting, tongue grafting, wedge grafting and crown grafting, depending

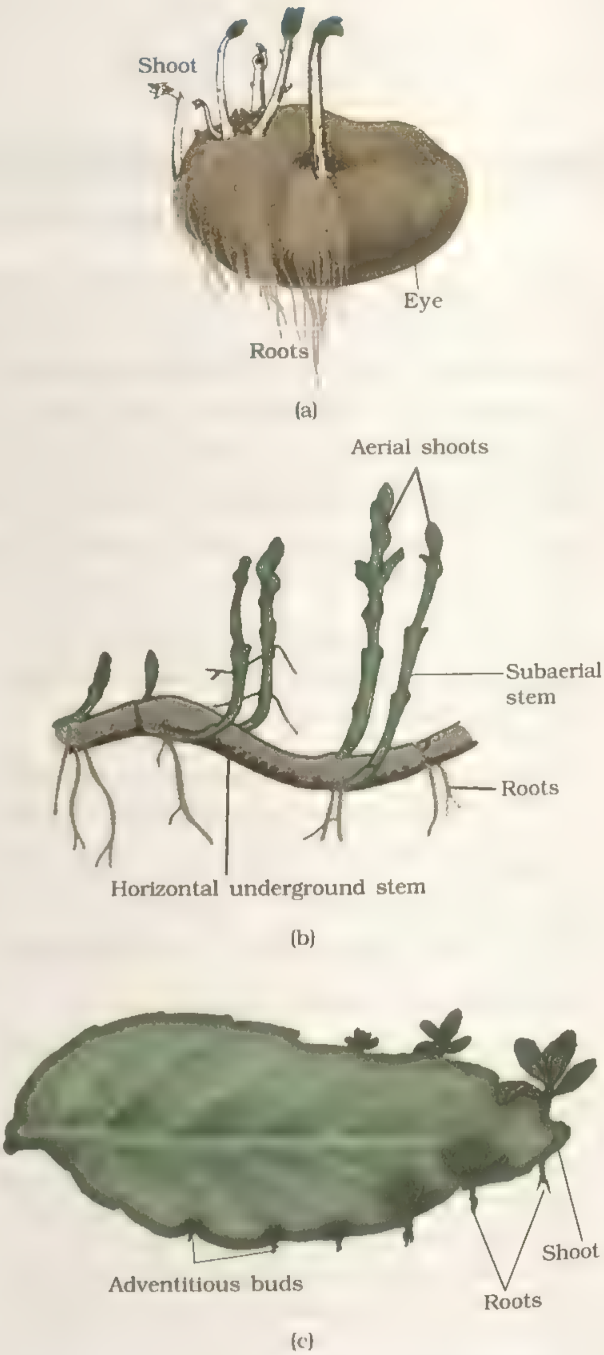


Fig. 12.1 *Parts of the plants used for vegetative reproduction : (a) underground stem, (b) subaerial stem, (c) adventitious bud*

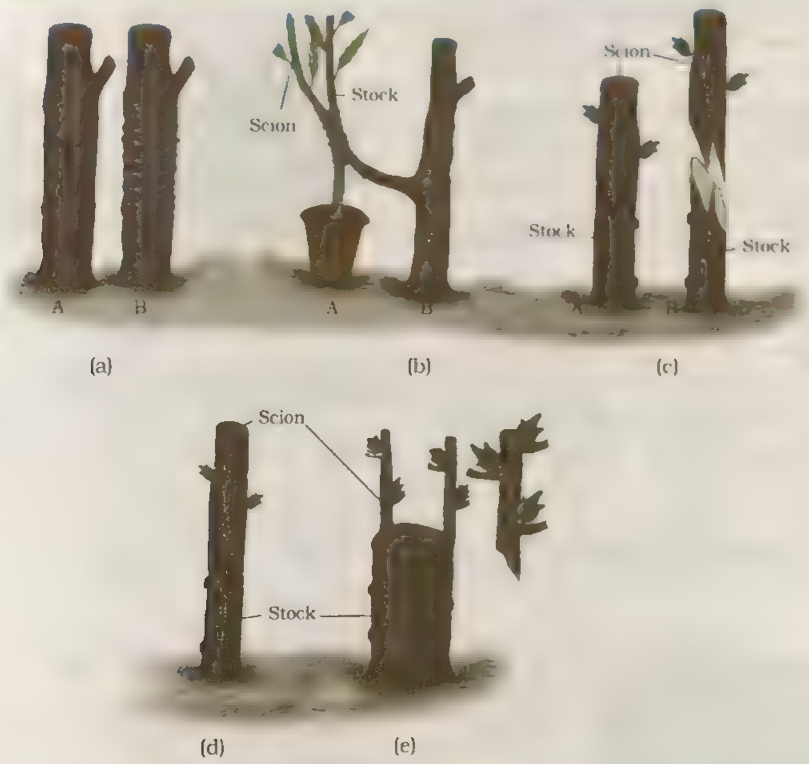


Fig. 12.2 *Types of grafting : (a) bud grafting, (b) approach grafting, (c) tongue grafting, (d) wedge grafting, (e) crown grafting*

on the methods of uniting the two parts (Fig. 12.2).

Gootee is a method usually employed for propagating lemon, orange, guava and litchi during the early monsoon rains. In this case, a healthy and woody branch is selected and the bark is sliced off in a ring form of about 3-5 cm in length. A thick plaster of grafting clay (clay, cow-dung, finely cut hay, and water) is wrapped up with rag and tied onto the debarked portion. A suitable arrangement is made for keeping the clay moist. In about 2-3 months, the roots emerge and the gootee is ready to be cut below the bandage for propagation.

Significance of Vegetative Reproduction

As stated earlier, plants in which useful characters of the parents have to be maintained, are propagated vegetatively. Plants with reduced power of sexual reproduction, long dormant period of seed or poor viability, are also multiplied easily through this method. Vegetative reproduction also helps in removing common infections from the parent plant. Grafting helps in getting an economically important plant having useful characters of two different individuals in a short time.

12.3 Sexual Reproduction

In the previous class, you have studied briefly about sexual reproduction in lower plants. In higher plants, sexual reproduction occurs by the fusion of male and female gametes present in the flower. You have studied earlier the

structure of the flower, and the constituent reproductive organs, stamen and pistil. Now, you will learn more about the reproductive process in angiosperms.

Development of the Male Gametophyte

Stamen, the male reproductive unit, is made up of the anther and the filament. The anther is generally bilobed, containing two longitudinally running chambers or pollen sacs per lobe. Each chamber contains several pollen grains. The anther wall is composed of four to five layers. The developing pollen grains consume the products of middle layers and tapetum, leaving behind the two layers, namely epidermis and endothecium (Fig. 12.3).

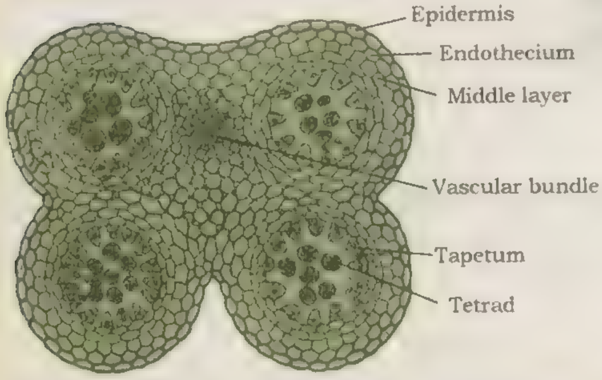


Fig. 12.3 *Transverse section of anther*

The mature anther dehisces by means of slits. The pollen grain is uninucleate with two-layered cell wall, as shown in Figure 12.4. The inner layer is thin and made up of cellulose, called **intine**, whereas the outer layer is tough, cuticularised and often with spinous outgrowth, known as **exine**. The exine is made up of a complex substance, called **sporopollenin**. At certain places, the exine is very thin or missing, giving an appearance of a pore, called the **germ pore**. There are usually three germ pores in dicots and one in monocots.

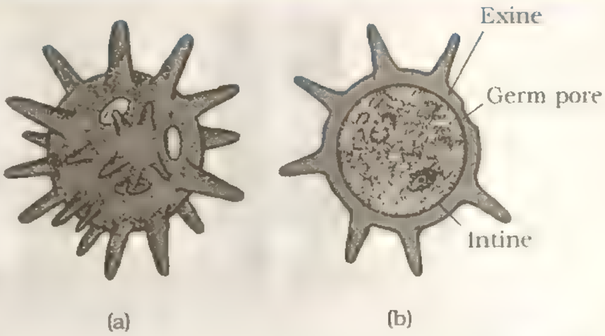


Fig. 12.4 *Structure of a pollen grain : (a) surface view, (b) sectional view*

The development of the male gametophyte is more or less uniform in all flowering plants. Pollen grain is the first cell of a male gametophyte. The size of the nucleus increases and it divides mitotically to produce a bigger vegetative cell and a smaller generative cell. At this stage, the dehiscence of the anther takes place and the two-celled pollen grains are released. After reaching the stigma, the intine grows out through a germ pore into a slender pollen tube. The generative cell divides into two male gametes. The life of male gametophyte is very short as compared to that of the sporophyte.

Development of the Female Gametophyte

A typical pistil consists of a basal swollen part (ovary), a stalk (style) and a terminal receptive disc (stigma). Inside the ovary, there are one or more ovules or **megasporangia**. The main body of the ovule consists of the **parenchymatous** tissue, the **nucellus**, with one or two coverings or **integuments**. The integuments surround the nucellus all around except at the apex, leaving a narrow passage, called the **micropyle** (Fig. 12.5).

The ovule at first arises as a primordium on the placenta in the cavity of the ovary. Owing to the meristematic activity of the cells of ovular primordia, the protuberances become

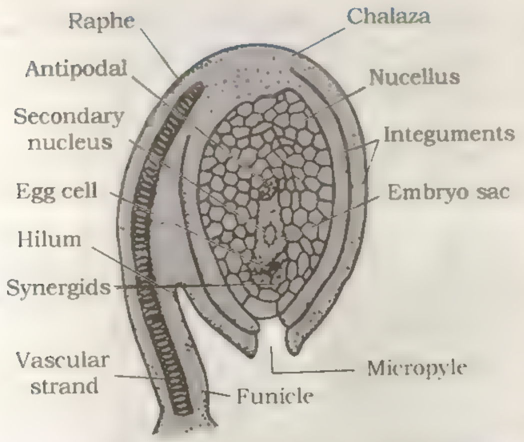


Fig. 12.5 *Longitudinal section of a mature ovule (anatropous type)*

prominent and constitute the nucellus. The initials of the two integuments arise at the base of the nucellus, and surround it all around except at the apex. The archesporial cell divides to form outer primary cell wall and inner primary sporogenous cell. This sporogenous cell directly behaves as the megaspore mother cell, and gives rise to four potential megaspores by meiosis. The four megaspores may be arranged in a linear tetrad. Usually, one megaspore of the tetrad becomes functional and develops further and the rest degenerate.

The functional megaspore is the first cell of the female gametophyte. It divides by three successive divisions to form an eight-nucleate female gametophyte or embryo sac [Fig. 12.6(h)]. Out of the eight nuclei, three get organised at the micropylar end as egg apparatus, three at the chalazal end as antipodals, and two at the centre as polar nuclei which fuse to form the secondary nucleus (2n). The egg apparatus consists of two synergids and an egg cell. This is monosporic type of development (Fig. 12. 6), generally referred to as the polygonum type. Panchanan Maheshwari, in 1950, classified the female gametophyte into monosporic, bisporic and tetrasporic embryo sac, depending upon the number of megaspore nuclei taking part in the development.

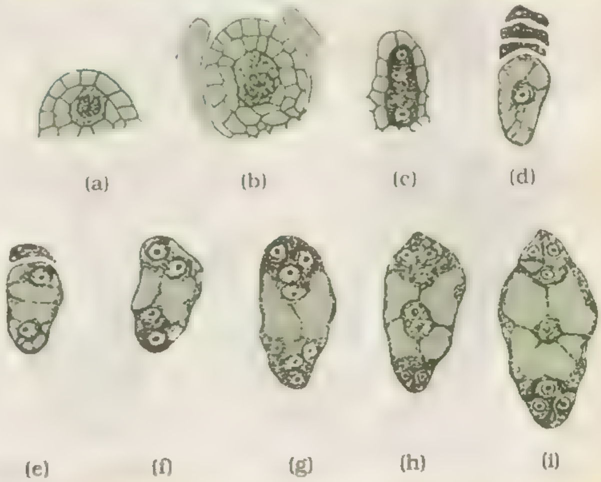


Fig. 12.6 *Development of the embryo sac*

Pollination

The word pollination refers to the process of transfer of pollen grains from anther and their deposition on to the stigmatic surface of the flower. If the pollen is transferred from anther to stigma of the same flower, it is called **self-pollination** or **autogamy**, as in pea, wheat and rice. In cases where pollen is transferred from anther of a flower to stigma of another flower of the same plant, it is referred to as **geitonogamy.** In plants, where the pollen move from the anther of one flower to the stigma of another flower of a different plant, it is termed **cross-pollination** or **xenogamy** or **allogamy**.

The process of transfer of pollen grains from anther to stigma can occur by air, water and animals, as illustrated in Figure 12.7.

The wind-pollinated flowers are generally unisexual, as in coconut palm, date palm, maize, many grasses, cannabis, etc. The pollen grains are produced in large quantities and are small, smooth and dry. The wind pollination

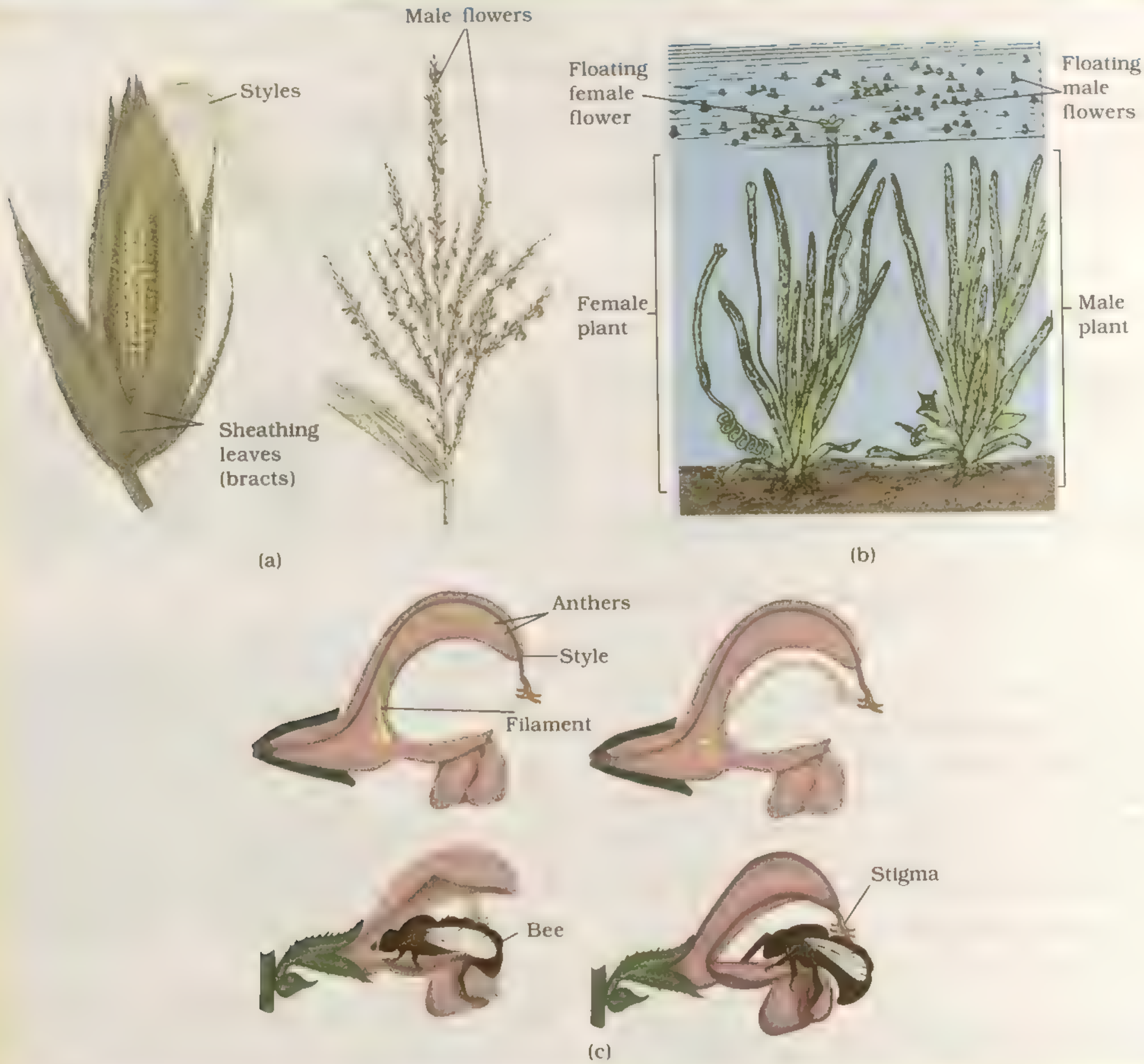


Fig. 12.7 *Pollination by different agencies : (a) air, (b) water, (c) animals – insects*

(**anemophily**) is not precise, as it involves the movement of pollen over long distances with respect to the direction of wind. The winged pollens of pines are found hundreds of kilometres away from the parent plants.

Water also acts as an agent of pollination; this is called **hydrophily** and is common in water plants, especially submerged ones, like *Vallisneria*, *Ceratophyllum* and *Zostera*. In these cases, the pollen is usually without an exine.

Animals are also responsible for pollination and this phenomenon is called **zoophily**. Insects are the most common pollinators, and this process is referred to as **entomophily**. The flowers producing nectar and fragrance, with bright colours, attract the insects. The flowers of Asteraceae and Labiatae families are

generally pollinated by the bees and butterflies. The pollination by birds, generally called **ornithophily**, is common in coral tree, bottle-brush, *Butea monosperma*, and silk-cotton tree. The pollination in *Adansonia* and *Kigelia* are carried out by bats (**chiropterophily**).

Need and Significance of Pollination

Pollination leads to fertilisation and production of seeds and fruits, which ensure continuity of plant life. The seeds and fruits are also a source of nutrition for animals, including humans. The pollination, especially cross-pollination results in the production of plants with a combination of characters from two plants. The role of pollination in the production of hybrid seeds has been of great significance.

Pollen Germination and Fertilisation

The pollen grains, after falling on stigma, start germinating in the presence of moisture and nutrients available on the stigmatic disc. The nucleus of the pollen grain divides to produce vegetative and generative cells. A short cytoplasmic outgrowth, called **germ tube**, emerges from the intine of the pollen and continues to grow as a pollen tube. It produces enzymes which digest the tissues of the stigma and the style. The nucleus of the generative cell forms two male gametes by mitotic division. The pollen tube finally enters the ovule through its micropyle and embryo sac through one of the synergids. Later on, the two male gametes are discharged in the embryo sac.

One of the male gametes fuses with the egg, resulting in the production of zygote. This is called **syngamy**. The second male gamete fuses with the secondary diploid nucleus, producing a triploid primary endosperm nucleus. This is called **triple fusion**. Thus, in an embryo sac there occur two sexual fusions : one in syngamy, and the other in triple fusion. This phenomenon is called **double fertilisation**.

Endosperm and Embryo Development

As stated earlier, the endosperm develops from the primary endosperm cell (3n) by its repeated mitotic divisions. Its development begins before the embryo development and is of three types, namely nuclear, cellular and helobial, as illustrated in Figure 12.8. In nuclear type, the nucleus undergoes repeated divisions, and nuclei so produced get arranged in the periphery, leaving a large central vacuole. Later, cytokinesis begins from the periphery towards the centre, making it cellular at maturity. This is the most common type and found in maize, wheat, rice, sunflower, etc. In the case of cellular type, every nuclear division is followed by cytokinesis, making it cellular from the beginning. In helobial type, the first mitosis is followed by cytokinesis, forming two unequal cells. Subsequent divisions are free nuclear. The endosperm becomes cellular after cytokinesis. In many dicots like pea, bean and sunflower, the endosperm is consumed by the developing embryo and is visible only as few cell layers in the mature seed, The albuminous seed, however, in many other plants, for example cereals, coconut, etc., endosperm enlarges considerably by cell division. and is much bigger than the embryo and persists in seeds.

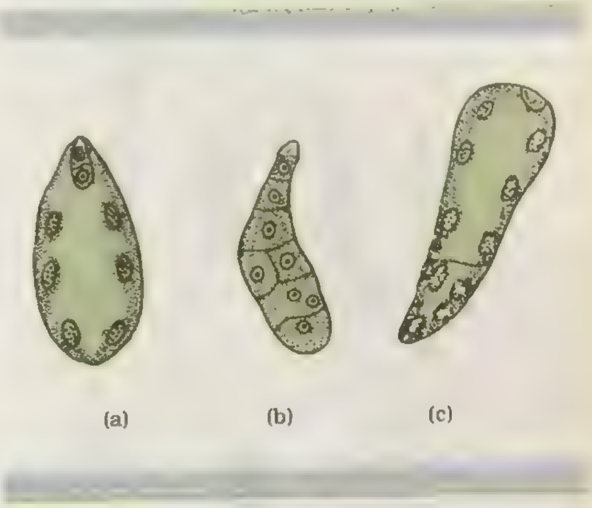


Fig. 12.8 *Types of Endosperm development : (a) free nuclear, (b) cellular, (c) helobial*

The zygote starts dividing to produce the embryo, together with the development of endosperm. It produces two cells : basal and terminal [Fig. 12.9 (b)]. The first division of the zygote produces a hypobasal cell (basal) towards the micropyle, and an epibasal cell (terminal) towards the chalaza (Fig. 12.9). The epibasal cell divides repeatedly to produce a row of 4-8 cells that constitute the suspensor. The terminal cell divides in various planes to produce a cluster of cells, called the **proembryo** [Fig. 12.9(d)]. The suspensor pushes the proembryo into the endosperm to enable the developing embryo to receive nutrition. A few cells of the proembryo nearest to suspensor develop into hypocotyl and radicle [Fig. 12.9(h)]. The other cells give rise to epicotyl, plumule and cotyledons. In dicots, two cotyledons are produced in the embryo, whereas in monocot plants, one of the two cotyledons gets suppressed at an early stage, leaving only one in the mature embryo. As the embryo and endosperm develop and mature, the integuments of the ovule become hard (to provide protective covering, as seed coat) and lead to the formation of seed. The seed dormancy and the process of seed germination are described in the next chapter.

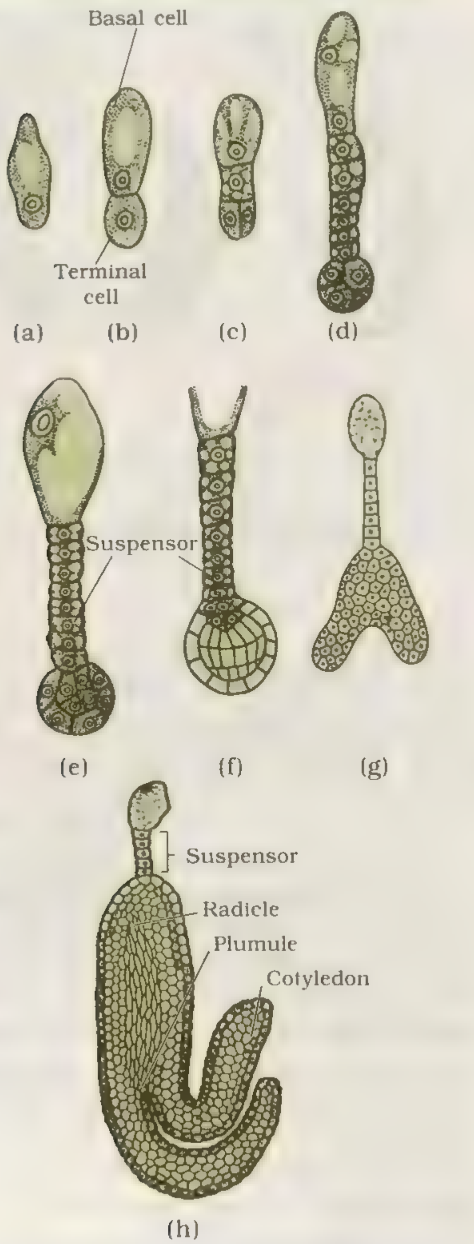


Fig. 12.9 *Embryo development in a dicot plant*

12.4 Incompatibility

Incompatibility is the inability of certain gametes, even from genetically similar plant species, to fuse with each other. This is also called **intraspecific incompatibility**, **self-sterility** or **self-incompatibility**. This may be due to some physiological or morphological mechanisms. It involves many complex mechanisms associated with interactions of pollen and stigmatic stylar tissues. If the incompatibility is due to the genotype of the sporophytic, it is termed **sporophytic incompatibility**. On the other hand, if it is due to the genotype of the pollen, it is termed **gametophytic incompatibility**. This may lead to prevention of pollen germination, retardation of growth, deorientation of pollen tube, or even failure of nuclear fusion. It is controlled by genes with multiple alleles. Usually, it develops with the maturation of stigma and during pollen wall formation.

12.5 Special Modes of Reproduction

The above described vegetative and sexual modes of reproduction are generally normal and occur in nature. There are cases where

propagation takes place even without the act of fertilisation. It may be by processes like **apomixis** and **polyembryony**. **Plant tissue culture** techniques are also being used extensively for propagation.

Apomixis is a modified form of reproduction, in which seeds are formed without fusion of gametes. It includes the process whereby a diploid cell of the nucellus develops into an embryo, giving a diploid seed with a genetic constitution identical to the parent. Apomixis is usually associated with polyploidy. The organism that can reproduce by apomixis is called an **apomict**. Another form of apomixis is **parthenogenesis**, in which seeds develop from unfertilised female gamete. Seeds produced in this way may be haploid or diploid, depending on the nature of the megaspore. **Parthenocarpy** is the development of fruit in an unfertilised flower, resulting in a seedless fruit. It may occur naturally, as in certain varieties of pineapple, grapes, apple, pear and banana. This may be induced by the application of hormones, as in tomato. Seeds may be formed either by the formation of a diploid embryo, embryo sac by a somatic cell, or by the suppression or modification of the process to produce an unreduced megaspore.

Sporophytic budding may sometimes occur in the nucellus and integuments, resulting in the development of an embryo. The examples are orange, mango, opuntia and onion. The embryo thus formed, is pushed into the embryo sac during the course of its development. Polyembryony is the presence of more than one embryo in the seed. It may be due to the presence of more than one egg cell in the embryo sac, or more than one embryo sac in the ovule, and all the egg-cells may get fertilised. In some cases, a number of embryos may develop simultaneously from different parts of the ovule, like synergids and antipodal cells, from fertilised or unfertilised egg-cell, or from the tissues of nucellus and integuments. Onion, groundnut, mango, lemon and orange are some of the examples for this phenomenon. Polyembryony is also very common in conifers.

The plant tissue culture also helps in propagating plants to a great extent. You will study the details about this in Chapter 24. In **micropropagation**, the cells, tissues or organs are detached from the plant to be propagated, and grown in a suitable artificial medium. *In vitro* (in test tube), these explants develop to form **callus**. This callus can be differentiated to produce plantlets, by supplementing the medium with hormones like auxin and cytokinin. This technique has been commercially used for the propagation of orchids, carnation, gladiolus and chrysanthemum. By this method, we can get unlimited number of plants in a limited space and short time, besides getting pathogen-free plants.

SUMMARY

The capacity to reproduce is one of the most important attributes of life and is aimed to preserve the individual species. Methods of reproduction are broadly grouped into asexual and sexual. In flowering plants, the asexual reproduction may be by the growth of detached vegetative parts, such as leaves, stems, roots and even buds. In this type of reproduction, the characters of the parent are completely preserved in the offspring. In the sexual method, there is a fusion of two gametes, one from male organ and the other from female organ of the plant, to produce a zygote. Sexual reproduction generally results in the mixing of characters from two parents, and maintains the general vigour of the offspring. In some plants, the modified vegetative parts, for example, roots modified into tuber (sweet potato), stem into rhizome (zinger, turmeric) and tuber (potato), can grow into new plants.

The leaf buds (*Bryophyllum*) and flowerbuds (*Oxalis*) also develop into new plants, after getting separated from the parent plant. Humans have developed some special techniques (artificial methods) to propagate the plant vegetatively from stem or root cuttings. The common techniques are layering, grafting, gootee and cuttings. Vegetative reproduction helps in maintaining useful characters of the parents, and overcoming the problems of weak sexual reproduction, long seed dormancy period, and poor viability.

The transfer of pollen grains and their deposition onto the stigmatic surface, is called pollination. It may be between the anther and stigma of the same flower or different flowers or even flowers from different plants. Wind, water, insects, birds and bats help in pollination. Pollination leads to fertilisation and production of seeds and fruits. The pollen grains germinate on the stigmatic surface. The nucleus of the pollen grain divides to produce vegetative and generative cells, and later on, male gametes. One of the male gametes fuses with egg cell (syngamy) and the other with secondary diploid nucleus. Thus, there is fertilisation at two places and it is referred to as double fertilisation.

The pollen grain is the first cell of the male gametophyte and produces two male gametes. Both male gametes are discharged into the embryo sac. The female gametophyte is generally eight nucleate, containing one egg cell and two synergids at the micropylar end, three antipodal cells at the chalazal end, and two polar or secondary nucleus. After fertilisation, the zygote divides and redivides to produce a proembryo, whereas the secondary nucleus forms a triploid endosperm. The proembryo finally develops into an embryo, which eventually gives rise to hypocotyl, radicle, epicotyl, plumule and cotyledons. The divisions during the development of endosperm may occur in different manner, and result in the production of nuclear or cellular or helobial type of endosperm.

In some cases, the gametes originating even from genetically similar plants, fail to fuse with each other. This is called incompatibility or self-sterility, and may be due to various physiological or morphological factors. Apomixis, polyembryony and plant tissue culture are also some of the methods for multiplication. Parthenogenesis, sporophytic budding and micropropagation (a type of tissue culture) are of great significance in getting large number of plants with useful characters in a short time.

EXERCISES

1. What do you understand by vegetative methods of reproduction? Explain with examples.
2. Describe the importance of artificial methods of vegetative reproduction.
3. Pollination is an important phenomenon in the life cycle of a flowering plant. Describe the agencies responsible for this.
4. Write short notes on the following :
   (a) hydrophily
   (b) entomophily
   (c) anemophily
   (d) cross-pollination

5. What do you understand by ornithophily and chiropterophily?
6. Write a note on the need and significance of pollination in plants.
7. What do you understand by double fertilisation?
8. Describe the structure of a pollen grain and the process of its germination.
9. Write an essay on the development of female gametophyte. Illustrate the answer with suitable diagrams.
10. Draw a well-labelled diagram of a mature ovule, showing its internal structure.
11. Describe the structure of a typical monosporic embryo sac found in flowering plants.
12. What do you understand by the development of an embryo? Support the answer with suitable diagrams.
13. Write a note on the development of endosperm. Mention the types with examples.
14. "Incompatibility is a natural barrier in the fusion of gametes." Justify the statement.
15. Describe in brief the various special modes of reproduction. Mention their economic significance.

Chapter 13

Plant Growth and Movements

Growth is one plant process with which all of us are familiar. If we sow a seed in the field or in a pot, it germinates and forms a tiny seedling which grows, over a period of time, into a much larger and heavier mature plant. Growth is an irreversible increase in size, weight and volume of an organism or its part. In plants, growth is associated with both anabolic and catabolic activities. It is usually confined to meristems and involves an increase in size and/or number of cells. Thus, growth is a quantitative phenomenon and can be measured in relation to time. Growth in living organisms is intrinsic and differs from extrinsic growth in non-living objects. Plants also show movements, both at organ-level, as well as whole-plant level. In this chapter, we will study the various aspects of growth, starting from dormancy and seed germination, characteristics and conditions for growth, its measurement, growth regulators, and types of movements in plants.

13.1 Dormancy and Seed Germination

In the previous chapter, you have studied about reproduction in flowering plants and formation of seed. The developed seed in many plants undergoes a period of dormancy before germination and further growth.

Almost all plants experience a period of suspended growth. The suspension of growth may be due to exogenous control, such as a change in environmental conditions, and is referred to as **quiescence**. However, many seeds may not grow even in favourable conditions. This is termed as **rest** or **dormancy**, and is under endogenous control. Thus, while quiescence is the condition of a seed when it is unable to germinate because favourable environmental conditions are not present, dormancy is the condition of the seed when it fails to germinate even though favourable environmental conditions are present. The dormancy in seeds may be due to rudimentary embryos, impermeable seed coats, mechanically resistant seed coats, physiologically immature embryos and even by the presence of germination inhibitors, like abscisic acid, phenolic acids, short-chain fatty acids and coumarin.

The dormancy of seeds can be broken or its duration can be reduced for early germination of seeds. This is possible by mechanical or chemical scarification of the seed coat, stratification of seeds (i.e., subjecting the moist seeds in the presence of oxygen for variable periods to low or high temperatures), or changing the environmental conditions, such as temperature, light and pressure.

Seed germination is the first step towards plant growth (Fig. 13.1). Seeds often wait for favourable signals and inputs from the environment to germinate. After the dormancy period is over or it is broken, and necessary conditions for growth are present, the dormant embryo resumes metabolic activities and growth. The process is called **seed germination.**

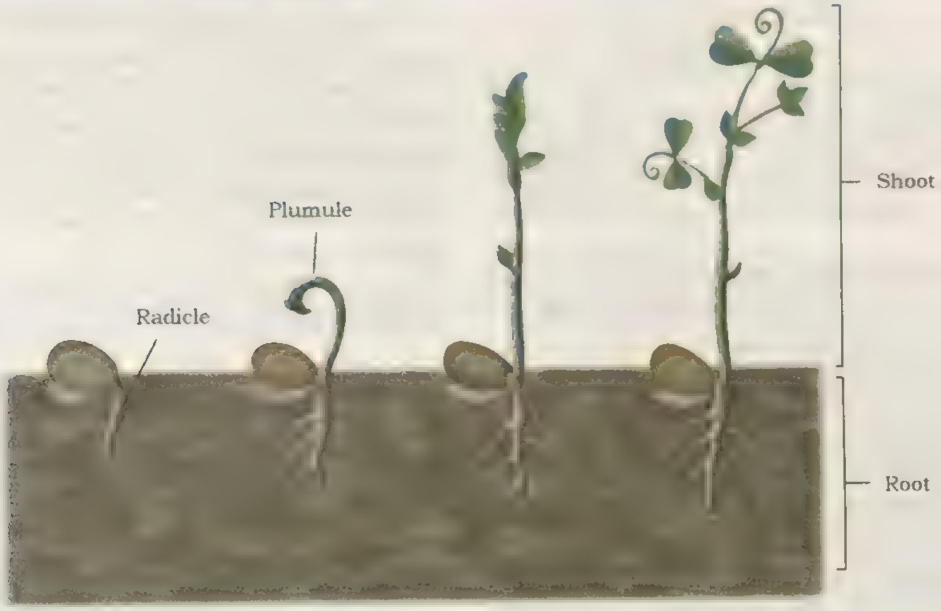


Fig. 13.1 *Germination of seed*

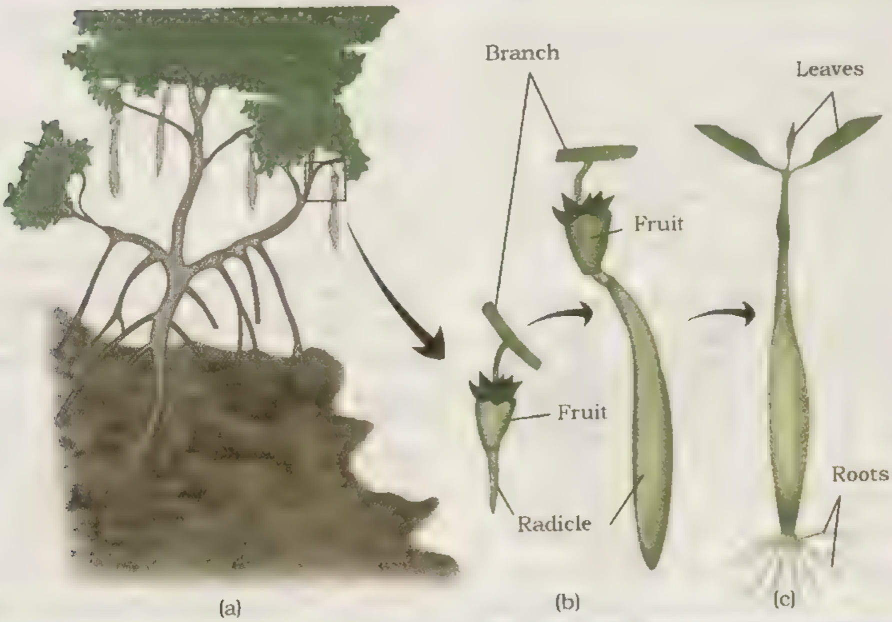


Fig. 13.2 *Viviparous reproduction in plant : (a) fruit attached to parent plant; (b) young plant growing in the fruit, (c) seedling on the ground*

The availability of water and oxygen is the essential condition for seed germination. The imbibition or uptake of water by the seed, is the first step. It causes the seed to swell, rupturing the seed coat to enable the radicle to emerge. The stored polysaccharides and proteins get hydrolysed to resume metabolic activities. The metabolic activities require oxygen for breaking down the reserve food and to release energy for various activities. In some plants, like certain varieties of lettuce and tobacco, light plays an important role in germination. The red region of the visible spectrum is most effective for the onset of seed germination.

The emergence of radicle from one end of the embryonic axis, which gives rise to the root system, is usually considered as a symbol of seed germination. At the other end of the embryonic axis is the plumule, which forms the shoot (stem and leaves). The growth of the radicle and the plumule involves cell extension and cell division, besides initiation of several biochemical processes. There is a rapid increase in the rate of respiration during germination. Some plants growing in marshy land, show a special type of germination known as **vivipary** as in *Rhizophora*, *Sonneratia* and *Heritiera* (Fig. 13.2). In vivipary, the seeds germinate inside the fruit, while still attached to the parent plant. The weight of the germinating seed increases, and thus, seedling separates and falls down vertically into the mud. The lateral roots develop quickly for proper anchorage.

13.2 Characteristics of Growth

Growth is one of the most important phenomena of all living organisms. Growth in plants occurs by cell division and cell enlargement, invariably followed by cell differentiation. The cell division generally occurs in apical regions of shoot and root. Thus, the meristematic cells present at shoot and root apices are responsible for growth in plants. The meristematic cells, in the form of cambium, are also present in vascular bundles of root and stem of dicot plants. They help in increasing the thickness of stem and root due to secondary growth. In some plants, the cambium may also be found just below the epidermis and above cortex, and is referred to as **cork cambium**.

The rate of plant growth is slow in the initial stages (lag phase), and increases rapidly later on (exponential phase). The growth again slows down due to the limitation of nutrients (stationary phase). If we plot the increase in number of cells as an indicator of growth against time, a typical sigmoid or S-shaped growth curve is obtained (Fig. 13.3).

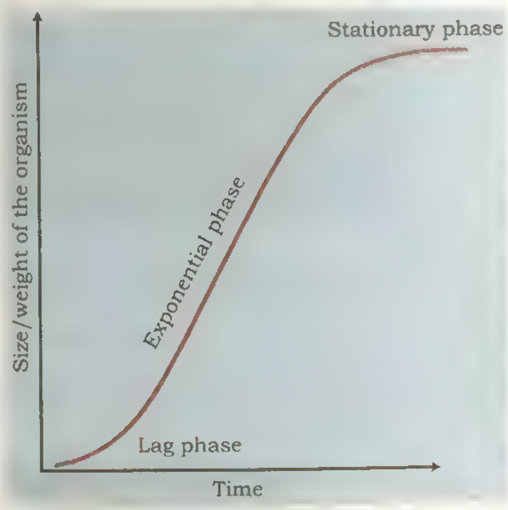


Fig. 13.3 *Growth curve*

The rate of growth can be measured by an increase in size or area of an organ of the plant, like leaf, flower, and fruit, in a unit time. The rate of growth is also called **efficiency index**.

13.3 Conditions for Growth

We know that growth is brought about by cell division and cell enlargement. The conditions necessary for growth are similar to that of synthesis of protoplasm and cell division. The supply of nutrients, water, oxygen, suitable temperature and light are necessary for proper growth. The force of gravity, and also light, determines the direction of root and shoot growth. Nutrients provide essential materials

for the synthesis of protoplasm and act as a source of energy. Water maintains the turgidity of growing cells and provides medium for enzymatic reactions. You know that oxygen is indispensable for respiration and for release of energy. Temperature has a thermotonic effect on growth and 28 to 30°C is an optimum range for proper growth in most cases. Temperature above 45°C coagulates and damages the protoplasm and hinders growth. Light is not essential during the initial stages of the growth, but is required for further growth and photosynthesis. There is a stimulating effect of light on plant growth, and its absence results in etiolation. Salt, mineral deficiencies and stress factors also influence the rate of growth.

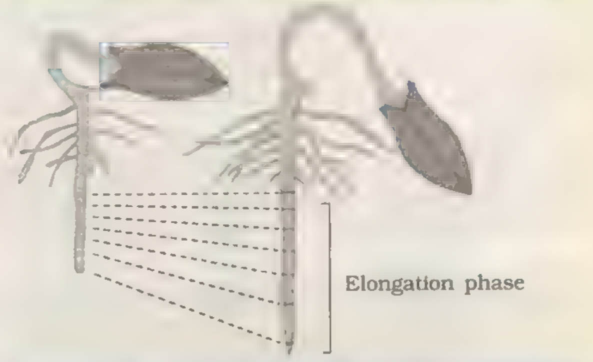


Fig. 13.4 *Growth in root*

13.4 Phases of Growth

We know that growth in plants is localised in the meristematic regions only, i.e., apical, lateral and even intercalary regions. The growth in length is due to enlargement and elongation of cells at the apical regions, and in thickness due to the activity of lateral and intercalary meristems.

The period of growth is generally divided into three phases, namely formative, elongation and maturation. The **formative phase** has constantly dividing cells and is restricted to the apical meristems, both at the root and shoot tips. The cells of this region are rich in protoplasm, with large nucleus and thin cellulose wall. The **phase of elongation** lies just behind the formative phase and is aimed at the enlargement of cells (Fig. 13.4). The **phase of maturation** is further behind, and here, the cells start maturing to obtain a permanent size. These phases are also known as regions. The time interval from the formative phase to maturation phase is called the **grand period of growth**.

13.5 Measurement of Growth

You know that growth is a natural phenomenon, and generally takes place at the apical regions of the plant. Thus, the growth in length can easily be measured with the help of ordinary measuring scale at an interval of time. For precise measurement, the equipment named **auxanometer** or **auxograph** can be used (Fig. 13.5). An auxanometer is used to

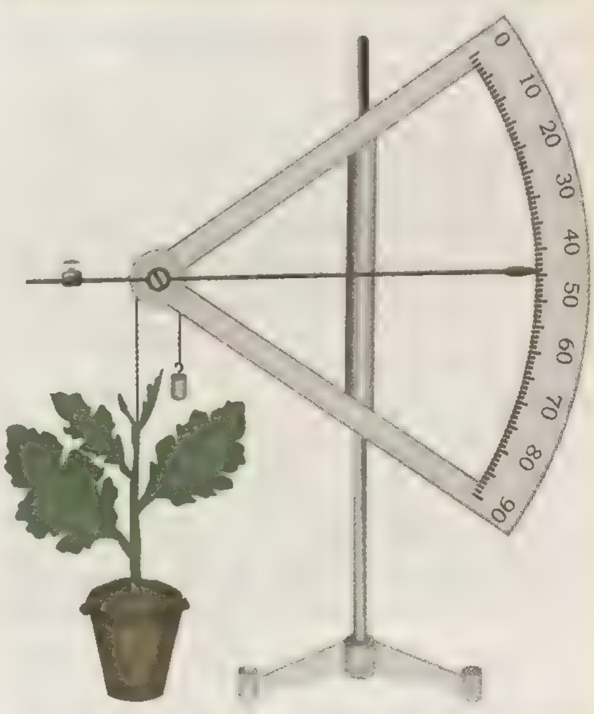


Fig. 13.5 *Arc auxanometer*

measure the rate of growth of a plant in terms of shoot length. A thread is tied to the growing tip of a potted plant, and at the other end, a weight is tied after passing the thread over a pulley. The needle attached in the centre of the pulley will show the deflection, which can be read on the graduated arc to find out the increase in length of the plant.

Growth can also be measured by an increase in weight, both fresh and dry, and volume of the plant. The increase in the number of cells, specially in algae, yeast and bacteria, also gives an idea about the rate of growth. The measurement of area or volume of an organ of the plant will also provide information about the rate of growth.

13.6 Growth Regulators

The analysis of growth curves provides an evidence of physiological control on growth. It is an established fact that plants produce some specific chemical substances, which are capable of moving from one organ to the other, so as to produce their effect on growth. These substances, which are active in very small amounts, are called **plant hormones**. They are organic compounds and are capable of influencing physiological activities leading to promotion, inhibition and modification of growth. These growth-regulatory substances are broadly grouped under five major classes, namely **auxins**, **gibberellins**, **cytokinins**, **ethylene** and **abscisic acid**. The other related growth regulators are jasmonic acid, salicylic acid and brassinosteroids. Some vitamins also regulate the growth of plants.

Auxins

Auxins (*Gk. auxein* : to grow), isolated initially from human urine, were the first plant hormones to be discovered. The term 'auxin' is applied to indole-3-acetic acid (IAA), and also to natural and synthetic compounds having similar functions such as growth regulating properties. Auxins are generally produced by the growing apices of the stem and root, from where they migrate to the region of their action. Auxins like IAA and indole butyric acid (IBA) have been isolated from plants. The synthetic auxins (2,4-dichlorophenoxy acetic acid – 2,4-D; naphthalene acetic acid - NAA) have also been used extensively, particularly in agricultural practices.

The compounds which can be converted into auxins are called **auxin precursors**, whereas the compounds which inhibit the actions of auxins are termed **anti-auxins**. The auxins which can easily be extracted are called **free auxins**, whereas auxins which are hard to extract and need the use of organic solvents are referred to as **bound auxins**. The free form of auxin is active, while the bound auxin is inactive in growth. A dynamic equilibrium exists between these two forms.

The functions of auxins can be tested with the help of bioassays. **Bioassay** means the testing of substance for its activity in causing a growth response in a living plant or its part. The test measures the concentration required to produce the effect, and thus, it is quantitative. The *Avena* curvature test, and root growth inhibition test are some of the bioassays for examining auxin activity (Fig. 13.6).

The applications of auxins have a wide range, like enhancing the formation of roots, development of parthenocarpic fruits, thinning of flowers and fruits for healthy growth of remaining ones, control of preharvest fruit drop, enhancing flowering, improving the quality during storage, weed control by herbicidal action, etc. Auxins characteristically control apical dominance.

Gibberellins

The discovery of gibberellins (GAs) was based upon the observations made in Japan in early 1800s on the 'bakane' or 'foolish seedling' disease of rice. The affected plants have a tendency to appear unusually tall, paler and thinner, and generally are without seeds. The disease was caused due to infection by an ascomycetous fungus, *Gibberella fujikuroi*. The active principle responsible for causing disease symptoms in rice was later identified from fungal extracts and called **gibberellin**. Subsequently, gibberellins were identified from other plants as well.

Chemically, gibberellins are different from auxins and contain a gibbane ring system with specific biological properties. There are

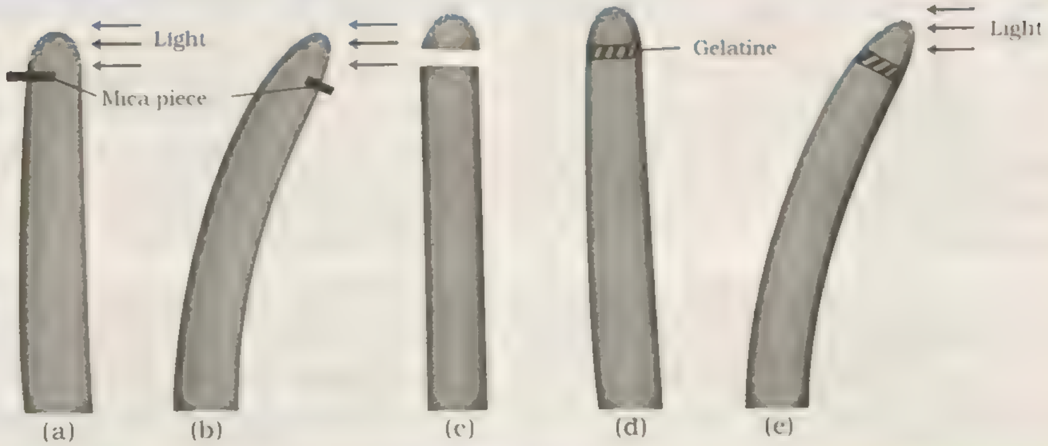


Fig. 13.6 *Avena test (a) A piece of mica inserted on the shaded side prevented curvature of the coleoptile, (b) but not when it was inserted on the illuminated side, (c) when the tip was removed, (d) but was put back with a block of gelatine, (e) normal phototropic curvature occurred*

more than 100 gibberellins reported from both fungi and higher plants, and the number is still increasing. They are denoted as GA_1, GA_2, GA_3 and so on. However, GA_3 was one of the first gibberellins to be discovered and remains the most intensively studied form. All GAs are acidic in nature and produce a wide range of responses, such as enhancing stem elongation and leaf expansion, breaking dormancy, promoting germination and flowering, and overcoming dwarfism. Gibberellins induce the production of enzymes, like amylases, proteases, lipases and ribonucleases, for mobilising storage reserves during seed germination and early seedling growth. Among these responses controlled by gibberellins, shoot elongation in some dwarf mutants and barley endosperm test (monitoring hydrolysis of starch by amylases during seed germination) are routinely used as bioassays.

Cytokinins

Cytokinins have specific effects on cytokinesis, and were discovered as kinetin (a modified form of adenine) from the autoclaved herring sperm DNA. Kinetin does not occur naturally in plants. The searches for natural substances with cytokinin-like activity led to the isolation of zeatin from corn kernels and coconut milk, etc. Since the discovery of zeatin, several naturally occurring cytokinins, and some synthetic compounds with cell division promoting activity, have been identified from plants. Cytokinins are synthesised in areas where cell division is occurring, for example root apices, developing shoot buds, young fruits, etc.

Cytokinins exert diverse effects on plant growth. They influence cell division, cell enlargement, differentiation, reduce apical dominance, and cause delay in senescence. The common bioassays for cytokinins include promotion of cell division in tobacco pith culture, expansion of excised radish cotyledons, delay in senescence (estimated by retention of chlorophyll), etc.

Ethylene

Ethylene is a simple gaseous hormone. It is synthesised in large amounts by tissues undergoing senescence and ripening fruits. Ethylene influences on plants include horizontal growth of seedlings, apical

hook formation in dicot seedlings, promotion of senescence and abscission of plant organs (leaves and flowers, etc). Ethylene is highly effective in inducing fruit ripening. Exposure of plants to ethylene causes drooping of leaves and flowers, a phenomenon known as **epinasty**. Ethylene is a natural product of metabolism in plants.

Abscisic Acid

Abscisic acid (ABA) was originally discovered for its role in regulating abscission and bud dormancy. But, like other plant hormones, it has been found to have multiple functions. It acts as a general inhibitor of growth and metabolism. Besides its role in abscission and bud dormancy, ABA inhibits seed germination and growth of excised embryos, inhibits growth in duckweeds, stimulates stomatal closure in epidermal strips, increases tolerance of plants to various kinds of stresses, etc. Abscisic acid plays a major role in seed development and maturation, enabling seeds to withstand desiccation and to become dormant. In most situations, ABA acts as an antagonist to gibberellins.

Vitamins

Vitamins (Vita : life) are a heterogenous group of biological products of plants. They have proved to be invaluable for normal growth and development of the organisms, maintenance of health and vigour. Thus, vitamins play a very important role in the metabolism of proteins, fats and carbohydrates and their proper assimilation in the body. Some vitamins act as prosthetic groups or coenzymes, and help in controlling important biochemical reactions in both plants and animals.

Vitamins are mostly synthesised by plants and stored in their different organs. Some vitamins can also be produced commercially. Vitamins are of many types, namely vitamins A, B (B complex – B_1, B_2, B_6, B_{12}, etc.), C, D, E and K. You have studied vitamins in detail with reference to humans in Chapter 5.

13.7 Photoperiodism

The impact of light and its duration on plant growth and development has been a field of great interest to scientists. It has been observed that some plants require the exposure of light for a period longer than the critical period for flowering, whereas some require less than critical period. Some other plants flower, irrespective of the duration of light exposure. The plants requiring longer exposure to light than their critical period, are called **long day plants**, whereas those requiring light for a shorter period than their critical period are **short day plants**, and the remaining come under the class of **neutral** or **intermediate day plants** (Fig. 13.7). In other words, in long day plants, flowering will be initiated only when the day length is longer than a critical day length, and in short day plants, flowering will begin only if the day length is shorter than a critical day length. We may also say that the length of darkness must exceed a critical dark period for the short day plants to flower. On the other hand, for the long day plants to flower, the period of darkness must be shorter than a critical dark period. Duration of the critical period varies among plant species and depends on many factors. Thus, the daily length of photoperiod plays a decisive role in the flowering process. The ability of the plant to detect and respond to the length of daily period of light or, more precisely, the relative length of day and night to which the plant is exposed, is called **photoperiodism**.

The short day plants include *Cosmos*, dahlia, *Chrysanthemum*, rice, etc. and are generally grown in the winter season. The long day plants are wheat, barley, sugar beat, larkspur, etc. Tobacco, cucumber, sunflower, tomato are some examples of the intermediate day plants. It has been hypothesised that there is a hormonal substance(s) called **florigen**, responsible for flowering, but the convincing experimental evidence in support of this is lacking. It is believed that this active principle is synthesised in the leaves, when the plants are exposed to the inductive photoperiod, and is translocated to the apical meristem for inducing flowering by conversion of vegetative meristem into reproductive meristem.

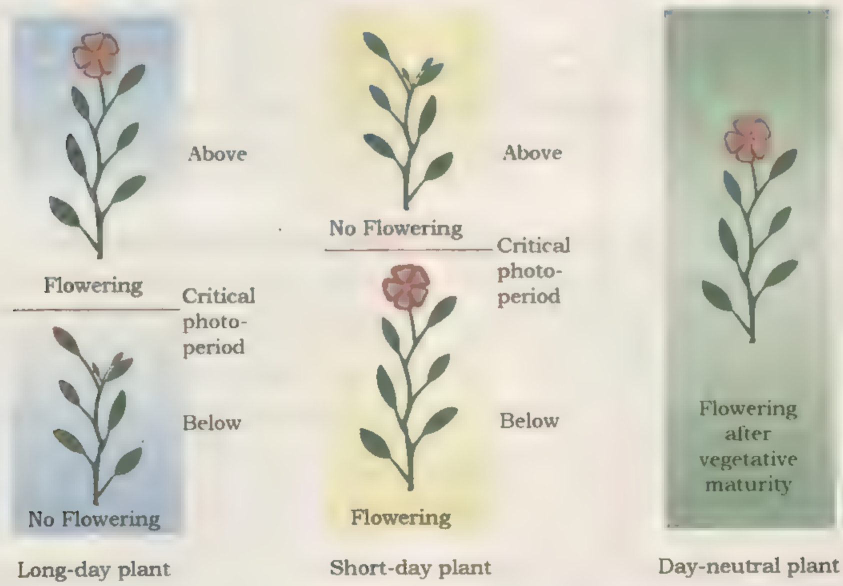


Fig. 13.7 *Photoperiodism – Long-day, short-day and day-neutral plants*

13.8. Vernalisation

The effect of temperature on growth of plants, specially flowering, has also been studied for long. It has been observed that plants from temperate regions require a period of low temperature before flowering takes place. The same effect on flowering has been observed if the soaked seeds are treated with a particular temperature for a certain period during their early stages of germination. The application of temperature between 1-10°C to certain varieties of wheat, rice, millets and cotton, accelerates the growth of seedlings and results in early flowering. This method of inducing early flowering by pre-treatment of seeds with a certain low temperature is known as **vernalisation**.

13.9 Senescence

Senescence is a period between complete maturity and death of an organ or organism. During this period, a gradual deterioration occurs in its structure and functioning, which is characterised by the accumulation of waste metabolic materials and decrease in dry weight. Generally, senescence implies the 'running down' of an organism or its parts. Senescence exists in all plants and at all stages of life cycle. There may be whole plant senescence, as in beans, tomato and cereals, or organ senescence, as in alfalfa, where the part above the ground dies each year and the root system stays alive. Thus, it is characterised by higher rate of catabolic activities and is controlled by some growth hormones.

13.10 Abscission

Abscission is shedding of leaves, fruits or flowers by a plant, generally due to a change in the hormonal balance. A separation (abscission) layer is developed within the region of attachment. The middle lamella between certain

cells in this layer, is often digested by polysaccharide-hydrolysing enzymes, such as cellulase and pectinases. Other degenerative changes also occur, making the region soft and weak. The organ from the plant is then easily detached whenever there is heavy rainfall or wind, etc. Abscisic acid plays an important role in this process.

13.11 Plant Movement

Unlike animals, plants remain fixed at one place and are immobile. However, certain kinds of movements do occur in plants, but these are generally too slow and remain unnoticed by the human eye. These can be observed at the interval of several hours by noting the changes in position of various organs.

Plastids in cells may show movements in response to light; stem of a plant grows upwards against the force of gravity or bends towards light. The streaming movement of protoplasm may be expedited due to temperature increase or exposure to light. In many cases, the stimuli affect many cells, in others there are special cells receiving stimuli. Thus, the ability to respond physically to an environmental factor is one of the basic properties of plants.

You know that there is no nerve system or special sense organs in plants, as in animals. The movements in plants are broadly classified as movements of locomotion and movements of curvature.

Movements of Locomotion

Locomotion is a movement of the protoplasm, which may be spontaneous or induced. Spontaneous (autonomous) movement may be at the level of protoplasm or organ, or even at the whole plant. The protoplasmic movements, accomplished by naked protoplasm in unicellular organisms, are generally divided into ciliary, amoeboid, cyclosis and gliding movements (Fig. 13.8).

The induced (paratonic) movement is the movement of complete cell or organelle, and is

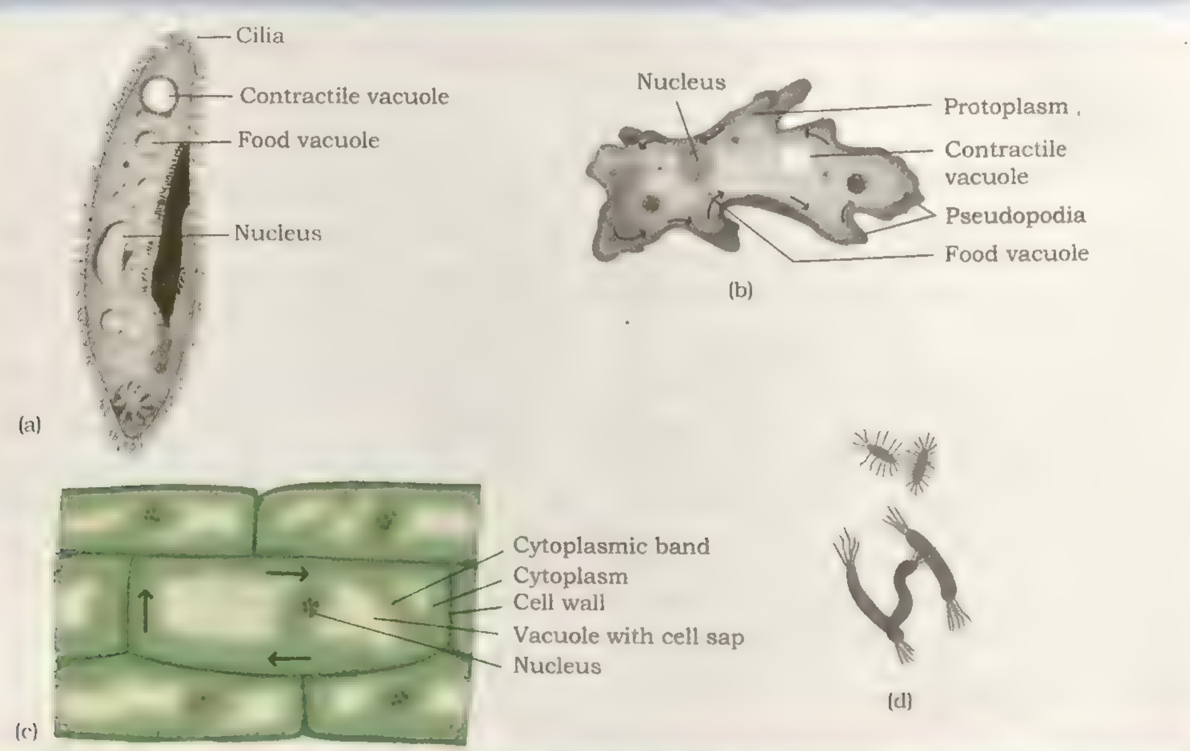


Fig. 13.8 *Protoplasmic movements : (a) ciliary, (b) amoeboid, (c) cyclosis, (d) gliding*

influenced by external stimuli. This is also called **tactic** (taxism or taxis) movement and is common among lower plants. The movement may be due to some chemical substances, such as sucrose and malic acid, present in the archegonium of ferns and moss, which attract spermatozoids; and mobile bacteria are attracted by peptone. The chemotactic agents operate via gradient-sensing mechanism, whereas chemo-receptors are periplasmic-binding proteins. Such movements are called **chemotaxis**.

Phototaxis is the movement in response to light. The weak light attracts and strong light repels the mobile algae. **Thermotaxis** is the tactic response to the stimulation by heat, as observed by the rapid circulation or rotation of protoplasm in the gently warmed tissues.

Movements of Curvature

The higher plants generally remain anchored at one place, and can change the direction of their organs by means of curvature. Thus, they put themselves in advantageous position for carrying out their functions more efficiently. Movements of curvature are **mechanical**, if they are the result of physical cause, like hydration or dehydration of cell walls, or **vital**, if caused by vital activities of living cells.

The movements caused by the vital activities of the living cells may also be spontaneous or induced. The spontaneous movements may be caused by the asymmetrical or differential rates of growth, referred to as **ephemeral type**. It may be due to the turgor changes, as observed in some leguminous plants and flowers, called **variation type**. **Movements of growth** are caused by the growing organs due to unequal growth. These are of epinasty, hyponasty and nutation types.

The movements of organs in response to stimuli are called **nastic** (nastism) or **tropic** (tropism) **movements**. When curvature is produced by diffused stimuli and affects the whole plant uniformly, it is of nastic type. If the curvature is produced by directive stimuli and does not affect the whole plant, it is of tropic type. The nastic movements are divided into photonasty, thermonasty, hydronasty, haptonasty, chemonasty and seismonasty, according to the factors involved (Fig. 13.9).

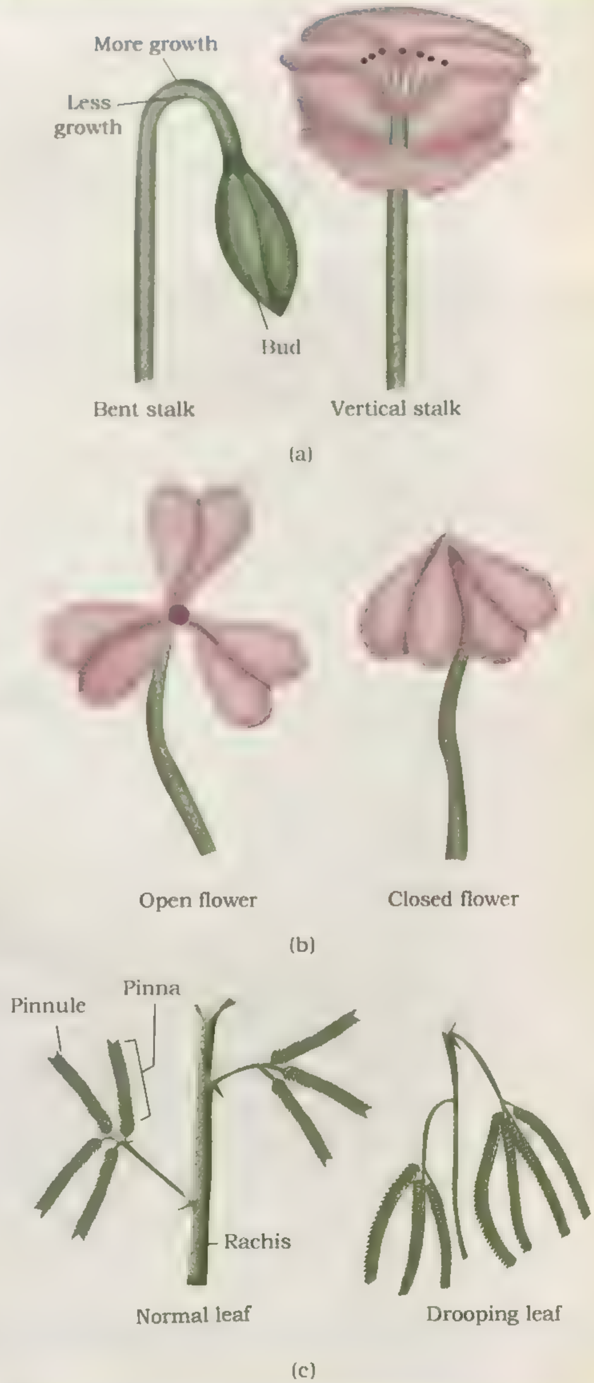


Fig. 13.9 *Nastic movements in plants : (a) epinasty and hyponasty, (b) photonasty, (c) seismonasty*

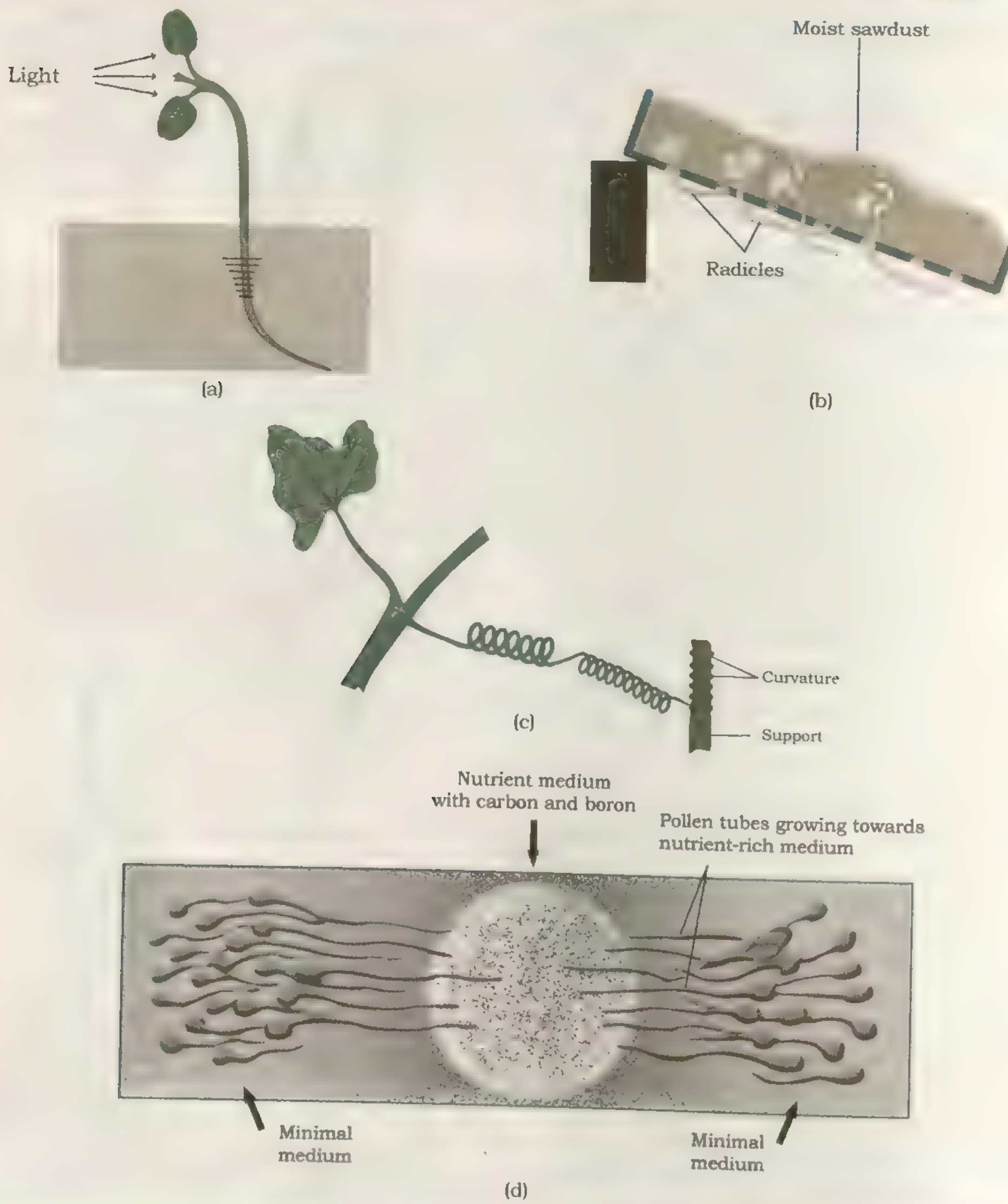


Fig. 13.10 *Tropic movements in plants : (a) phototropism, (b) hydrotropism, (c) thigmotropism, (d) chemotropism*

The tropism shows a definite direction in relation to the stimuli like water, chemical, contact, gravity, light, etc. This is also divided into various groups, namely hydrotropism, geotropism, phototropism, chemotropism, thigmotropism, etc., on the basis of types of stimuli the plants receive (Fig. 13.10).

SUMMARY

The irreversible increase in shape, size and weight of an organism or its part is called growth. In plants, it is generally confined to apical regions and in meristematic tissues. Almost all the plants experience a period of suspended growth and even a period of rest, which is referred to as dormancy. The dormancy in seeds may be due to impermeable and mechanically resistant seed coat, physiologically immature and rudimentary embryo, or even due to the presence of inhibitors. Dormancy can be broken or its period can be reduced by mechanical or chemical scarification of seed coat, stratification of seeds, and by changing the environmental conditions. In some cases, light plays an important role in seed germination. Cell division and cell enlargement, followed by cell differentiation, result in growth. The rate of growth is slow in the beginning, rapid thereafter, and then becomes stationary. The rate of growth of a plant or its organs can be measured with the help of an instrument, called auxanometer. The period of growth is generally divided into formative, elongation and maturation phases.

Plants synthesise some organic compounds, called hormones. Even in very small amounts, they influence the physiology of plants and are responsible for growth. These growth-regulatory substances are broadly grouped under five major categories, namely auxins, gibberellins, cytokinins, ethylene, and abscisic acid. Jasmonic acid, salicylic acid, brassinosteroids and some vitamins also help in regulating the process of growth. Auxins are involved in regulating apical dominance, cell elongation, cell division in cambium and root induction, etc. Gibberellins are especially useful in enhancing seed germination, cell elongation and flowering, overcoming dwarfism, besides other general functions. Cytokinins play a key role in cell division, and specially help in delaying senescence and reducing apical dominance. Ethylene and abscisic acid generally have a negative role and are responsible for immature falling of leaves, rapid fading of flowers, inhibiting germination, etc. Sometimes, their negative role becomes beneficial for us, as inducing fruit ripening, breaking dormancy in potato, inhibiting the growth of duckweeds and stimulating the closure of stomata. Vitamins have proved to be invaluable for normal growth and development of plants.

Flowering in plants has a close relationship with the period of exposure to light. Some plants flower in longer periods of exposure to light, whereas others in shorter photoperiods. Some flowering plants are neutral towards the duration of light. Low temperature, in particular, has profound effect on growth and flowering of plants. This effect is referred to as vernalisation. The period between complete maturity and final death of an organ or organism is termed senescence. Abscission is shedding of leaves, flowers or fruits by a plant.

The movement in plants is very slow and can be observed at the interval of several days. The streaming movement of protoplasm is spontaneous, whereas the movement in plastids is due to light. Induced movements are referred to as taxis and may be due to chemical, light and heat. In some cases, the curvature is produced by diffused stimuli and influences the whole plant uniformly. This is referred to as nastic movement or nastism. In others, the stimuli do not affect the whole plant and the curvature developed is termed tropic movement or tropism. The stimuli that trigger movement in plants are light, heat, water, touch, chemical, gravity, etc.

EXERCISES

1. What is dormancy? How does it differ from quiescence?
2. Describe the various steps involved in the process of seed germination.
3. "Growth is an important phenomenon of living." Justify the statement with reasons.
4. What are the important characteristics of growth? Describe in brief.
5. Explain different phases of growth with the help of a diagram.
6. How will you measure the rate of growth? Describe an instrument used to measure the increase in height of an angiospermic plant.
7. Write an essay on growth regulators in plants.
8. "The role of ethylene and abscisic acid is both positive and negative." Justify the statement.
9. What do you understand by photoperiodism and vernalisation? Describe their significance.
10. Write short notes on the following :
    (a) Senescence
    (b) Abscission
    (c) Quiescence
    (d) Vivipary
11. What do you understand by the spontaneous and induced movements in plants? Illustrate your answer with suitable diagrams.
12. What is the difference between :
    (a) Nastic and tropic movements
    (b) Phototropism and geotropism

Chapter 14

Reproduction and Development in Animals

Recall that the molecules of nucleic acids are self-duplicating; the cells divide by mitosis or meiosis. At the individual level, organisms employ a wide range of methods for reproduction. Acellular (single-celled) protist animals reproduce by a relatively simple method, whereas multicellular animals reproduce by complex methods. In this chapter, you will be familiarised with the major types of reproduction in animals. This will be followed by a description of human reproductive systems. Finally, the events of human reproduction, leading to the formation of the embryo and its subsequent development into a young individual, will be explained to give you an idea about the basics of embryonic development.

14.1 Major Types of Reproduction

Animals reproduce by two fundamental methods : asexual and sexual. In **asexual reproduction** a single parent is involved. In this method, a single-celled or many-celled parent individual either splits, or buds or fragments into two identical daughter cells or individuals. For example, many acellular protists, such as *Amoeba*, *Paramoecium*, *Euglena*, and multicellular metazoans, such as *Sycon*, *Hydra*, *Tubularia*, *Planaria*, *Ascidia*, reproduce primarily by asexual means. In **sexual reproduction**, two parents, each capable of producing gametes, spermatozoa and ova, are required. Many acellular protists, like *Monocystis*, *Plasmodium*, *Paramoecium*, and all metazoans employ sexual reproduction.

14.2 Asexual Reproduction

There are three common modes of asexual reproduction : fission, budding and fragmentation. In **fission**, the nucleus divides first and the cytoplasm next. Subsequently, the mother cell splits into two equal sized daughter halves or cells (e.g., *Amoeba*, *Paramoecium*, *Euglena*, *Vorticella*, *Planaria*, etc.). This is referred to as **binary fission**. When the plane of cytoplasmic division passes through any direction (e.g., *Amoeba*), the fission is called **simple binary fission** (Fig. 14.1). If the plane

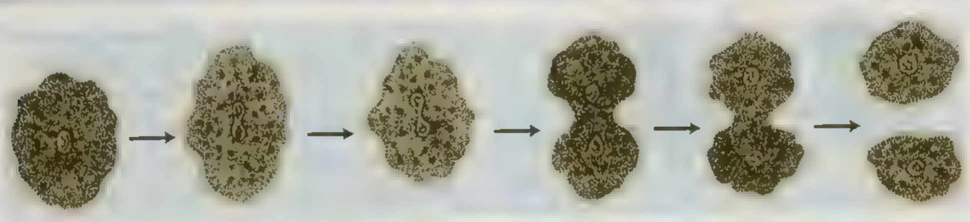


Fig. 14.1 *Simple binary fission in Amoeba*

of cytoplasmic division coincides with the transverse axis of the individual, as in *Paramoecium* and *Planaria*, the fission is termed **transverse binary fission** (Fig. 14.2).

Binary fission involves mitosis only and, consequently, the resultant offsprings are genetically identical to the parent and to each other. It may be mentioned here that genetically

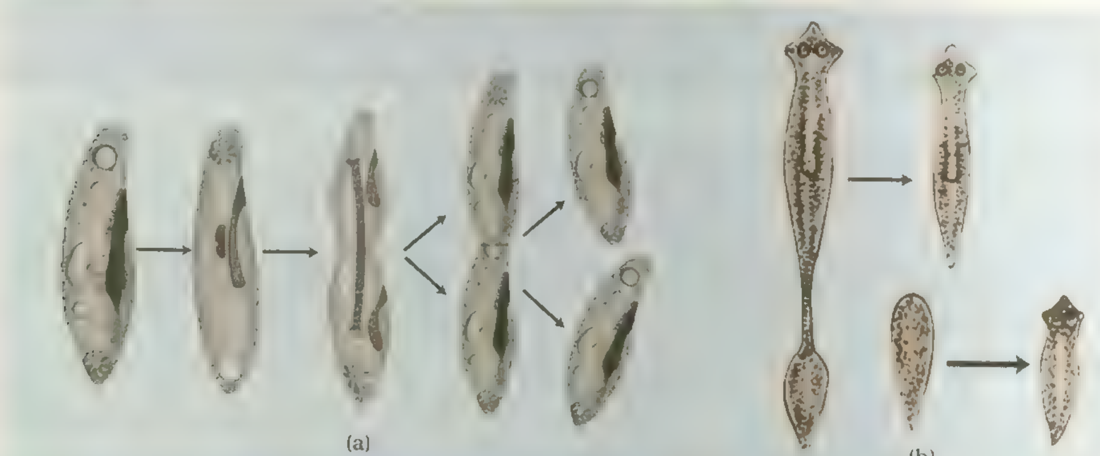


Fig. 14.2 *Transverse binary fission in (a) Paramoecium, (b) Planaria*

In *Euglena* and *Vorticella*, the plane of cytoplasmic division coincides with the longitudinal axis of the individual. This kind of fission is designated as **longitudinal binary fission** (Fig. 14.3).

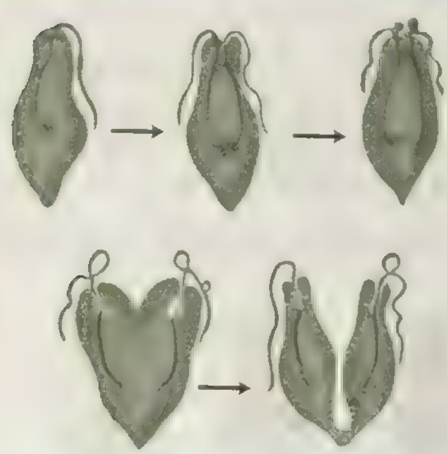


Fig. 14.3 *Longitudinal binary fission in Euglena*

identical offsprings resulting from a single parent are considered as **clones**. Nevertheless, the members of a clone may differ genetically when there is a sudden heritable change, i.e., mutation. Today, the scientists have been able to produce clones of multicellular animals (e.g., boar calf named as Frosty, and Finn Dorset lamb named as the famous Dolly) artificially in the laboratory.

Sometimes, the nucleus divides several times by **amitosis** to produce many nuclei, without involving any cytokinesis. Later, each nucleus gathers a small amount of cytoplasm around it and the mother individual splits into many tiny daughter cells (e.g., *Amoeba*, *Plasmodium*, *Monocystis*, etc.). In course of time, each of these daughter cells starts a free life and transforms into an adult individual. This kind of fission is called **multiple fission**. In response to unfavourable living condition, an *Amoeba* withdraws its pseudopodia and secretes a three-layered hard covering or **cyst** around itself. This phenomenon is termed as **encystation**. During favourable condition, the encysted *Amoeba* divides by multiple fission

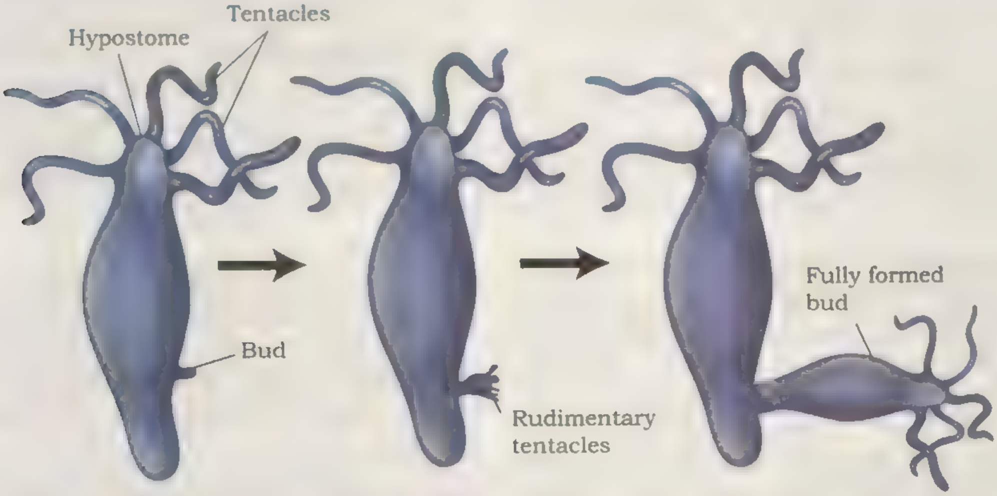


Fig. 14.4 *Exogenous budding in Hydra*

Fig. 14.5 *Internal buds in Spongilla*

and produces many minute amoebae or **pseudopodiospores**; the cyst wall bursts out, and the spores are liberated in the surrounding medium to grow up into many amoebae. This phenomenon is known as **sporulation**. Acellular protists like sporozoans (e.g., *Monocystis*, *Plasmodium*, etc.) typically exhibit sporulation in their life cycles.

In **budding**, new individuals are formed by mitosis of some cells of the mature individual. Initially, a small outgrowth of the parent's body develops into a miniature individual. It then separates from the mother to lead a free life (e.g., *Hydra*). This type of budding is recognised as **exogenous budding** (Fig. 14.4). Sometimes, the buds do not get separated from the mother individual and form a **colony**. For example, in *Obelia*, the colony consists of a number of individuals or zooids that perform different functions. In fresh water sponges (e.g., *Spongilla*) and marine sponges (e.g., *Sycon*), the parent individual releases a specialised mass of cells enclosed in a common opaque envelope, called the **gemmule** (Fig. 14.5). On germination, each gemmule gives rise to an offspring. Gemmules are thought to be **internal buds**.

In **fragmentation**, the body of the parent breaks into distinct pieces, each of which can produce an offspring (e.g., *Hydra*, some marine worms, sea-stars). This capacity for generating an entire new individual from a fragment of tissue is called **regeneration**.

14.3 Sexual Reproduction

In sexual reproduction, the haploid **gametes**, spermatozoa and ova, fuse to produce a diploid **zygote**. Consequently, the offspring of sexually reproducing organisms receive a set of genes from each of the parents. In other words, sexual reproduction introduces new gene combinations in a population. The diploid zygote then divides by mitosis, and after passing through the different phases of ontogenetic development, transforms into a new multicellular individual. Some acellular protist animals (e.g., *Paramoecium*) exhibit sexual reproduction by forming male and female **gamete nuclei**, which they exchange through temporary cytoplasmic bridge; later, the cytoplasmic bridge disappears and the gamete nucleus of one individual fuses with that of the other to form zygote nuclei. This mode of sexual reproduction is known as **conjugation**.

14.4 Deviations in the Reproductive Strategies

Although asexual and sexual reproductions are the two major trends of breeding, many deviations are also observed in the reproductive strategies of animals. One such variation in reproductive strategy is **hermaphroditism**, found in tapeworms and earthworms. Tapeworms are self-fertilising; the sperm produced in the testes of one individual can fertilise the eggs produced by the same individual. The earthworms employ cross fertilisation; the sperm of one individual fertilises the eggs of the other.

Another important reproductive strategy is the development of unfertilised ovum into a new individual. This phenomenon is referred to as **parthenogenesis** [*Gk.* : Virgin birth]. Charles Bonnet (1745) discovered parthenogenetic development in insects (aphids). As the egg develops without meiosis, the offsprings are identical in all inherited respects to the mother. Rotifers, some gastropod molluscs, many arthropod crustaceans, and even the lizards, take up parthenogenesis as a natural phenomenon. In certain rotifers, the existence of male is still unknown. In 1936, Gregory Pincus induced parthenogenesis in mammalian (rabbit) eggs by temperature change and chemical agents.

14.5 Human Reproductive System

In human beings, reproduction takes place by sexual method and the **sexes** are separate. The primary sexual organs of males and females are the **testes** (*sing.* testis) and the **ovaries** (*sing.* ovary), respectively. The males are also different from the females in their secondary sexual features or accessory sex organs. Thus, the humans exhibit **sexual dimorphism**. For example, the mammary glands are well developed in the females and rudimentary in males; the females do not develop beard and moustache but males do; the voice in females is pitched higher than in males.

The Male Reproductive System

The human male reproductive system (Fig. 14.6) is composed of a pair of testes, genital

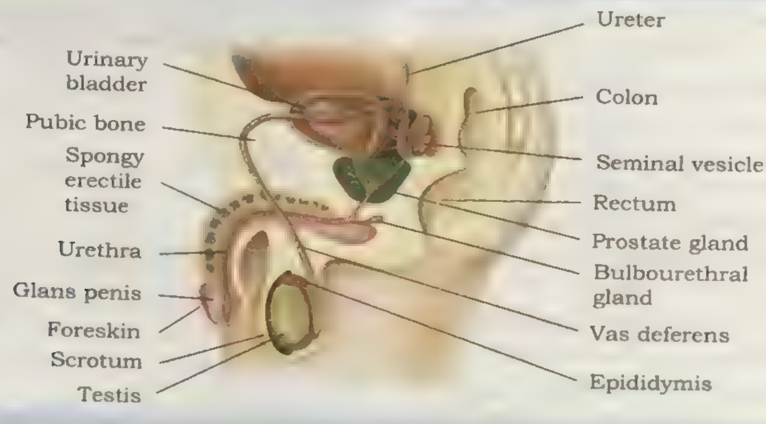


Fig. 14.6 Structure of human male reproductive system

ducts, several accessory glands and penis. In adult males, each **testis** is a small, pinkish and oval, but composite structure, about 5 cm in length, 2.5 cm in width and 3 cm in thickness. Each testis is a compound tubular gland and remains packed with numerous (about one thousand) highly coiled **seminiferous tubules**. The seminiferous tubules are situated in the regions of the testes, called **testicular lobules**. They are enclosed in an outer tough capsule of collagenous connective tissue, the **tunica albuginea**. The seminiferous tubules consist of a tunic of fibrous connective tissue, a well-defined basal lamina and a complex **germinal** or **seminiferous epithelium** (Fig. 14.7). The provide shape and nourishment to the developing spermatogenic cells. Spermatogenic cells are stacked in 4-8 layers that occupy the space between the basal lamina and the lumen of the tubule. These cells divide several times and differentiate to produce spermatozoa. Between the seminiferous tubules lie the **interstitial cells** or **Leydig cells**, named so after a German anatomist, Franz von Leydig (1821-1908), who discovered them. These cells secrete testosterone hormone that controls spermatogenesis.

Both the testes are held in a pouch, the **scrotum**, which is an outpocketed sac of the abdominal or pelvic cavity; it hangs from the

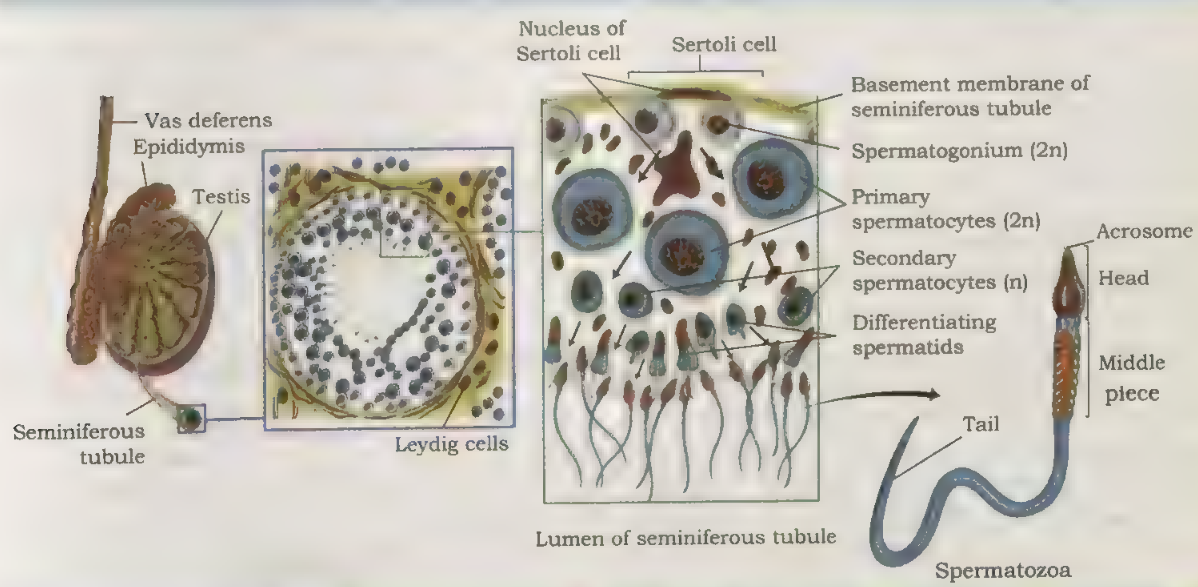


Fig. 14.7 *Transverse section of testis showing seminiferous tubules and various stages of spermatogenesis*

epithelium consists of two types of cells : **Sertoli** or **supporting cells** and **spermatogenic cells**. Sertoli cells are so named after the discoverer, Enricho Sertoli (1842-1910), an Italian histologist. These cells are elongated and pyramidal and partially envelop the spermatogenic cells. The bases of the Sertoli cells adhere to the basal lamina, and their apical ends frequently extend into the lumen of the seminiferous tubules. Sertoli cells groin. Hence, the testes of human males are called **scrotal** or **extra-abdominal testes**. However, the scrotum remains connected with the abdomen or pelvic cavity by the **inguinal canals**. While descending from the abdomen, the testes pull their blood vessels, nerves and conducting tubes after them. The cremaster muscles and connective tissue that form the **spermatic cord**, encase all these structures. Tearing of inguinal tissue by any means may

result in the bulging out of a loop of intestine into the scrotum. This condition is known as **inguinal hernia**. The temperature of scrotum is congenial for sperm production, as it is lower by 2°C than the normal body temperature (37°C).

Most seminiferous tubules are in the form of loops, both ends of which continue in short segments of straight tubules, the **tubuli recti**. These tubules connect the seminiferous tubules to a highly anastomosing labyrinth of cuboidal epithelium-lined channels, the **rete testis**. From the rete testis arise 10-20 fine tubules, **ductuli efferentes**. Tubuli recti, rete testis and ductuli efferentes form the **intra testicular genital duct systems**. The tubules of ductuli efferentes combine to form the **ductus epididymis**. Each epididymis consists of a single convoluted tube, about 6 metre long, which is highly coiled and leads into a sperm duct, the **ductus deferens** or **vas deferens**. The ductus deferens is a straight tube with a thick, muscular wall; it passes through the inguinal canal into the pelvic cavity. The ductus deferens forms part of the spermatic cord mentioned earlier. Before entering the prostate, the ductus deferens dilates to form the **ampulla**. The final portion of the ampulla receives the seminal vesicle of its side. From this point, the ductus deferens enters the single prostate gland and continues as **ejaculatory duct**. The prostate opens into the prostatic **urethra**, which emerges from the urinary bladder. The urethra, in turn, passes through the penis and empties to the exterior. The ductus epididymis, the ductus (vas) deferens and the urethra transport the spermatozoa toward the **penile meatus** and, thus, constitute the **excretory genital ducts**.

The **seminal vesicles** are long pouches with muscular wall; they secrete spermatozoa activating substances, such as fructose, citrate, inositol, prostaglandins and several proteins. About seventy per cent of human ejaculate (semen) is contributed by the seminal vesicles. The products of the testes (spermatozoa) and prostate gland, along with the fluid from the seminal vesicle, are collectively known as **semen**. The prostate gland is of the size of a golf ball and is spongy in texture. It is a collection of 30-40 tubuloalveolar glands whose secretions, the prostatic fluid, empty into the prostatic urethra at the time of ejaculation. The **bulbourethral glands (Cowper's glands)**, located proximal to the membranous portion of the urethra, also open into the urethra. They are also tubuloalveolar glands that secrete clear mucus for lubrication. The seminal vesicles, the prostate and the bulbourethral glands constitute the **accessory genital glands**.

The **penis** is an erectile copulatory organ. It consists of a long shaft that enlarges to form an expanded tip, the **glans penis**. Under the skin, the penis contains three columns of erectile tissue : two cylinders of the **corpora cavernosa** of the penis, placed dorsally, and one cylinder, the **corpus cavernosum** of the urethra or **corpus spongiosum**, along the ventral side (Fig. 14.8). The corpora cavernosa of the penis and the urethra are covered by dense connective tissue, the **tunica albuginea**. Both urine and semen are carried out of the body through the penis. The accessory genital glands, along with their duct systems and the penis, form the **secondary sexual organs** of man.

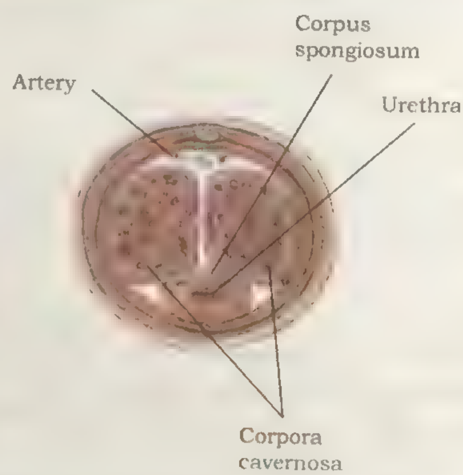


Fig. 14.8 *Transverse section of human penis*

The human male reproductive system performs two major functions : spermatogenesis (formation of spermatozoa) and transfer of sperm to the reproductive tract of the female.

The Female Reproductive System

The female reproductive system (Fig. 14.9) consists of two ovaries, two oviducts (uterine tubes), the uterus, a vagina and the external genitalia, accessory genital glands and the mammary glands. The **ovaries** are almond-shaped bodies, about 3 cm long, 1.5 cm wide and 1 cm thick. Each ovary is located close to the lateral walls of the pelvic cavity, being suspended from the dorsal body wall just behind the kidney by a section of peritoneum, the **mesovarium**; it is held in position by several connective tissue ligaments.

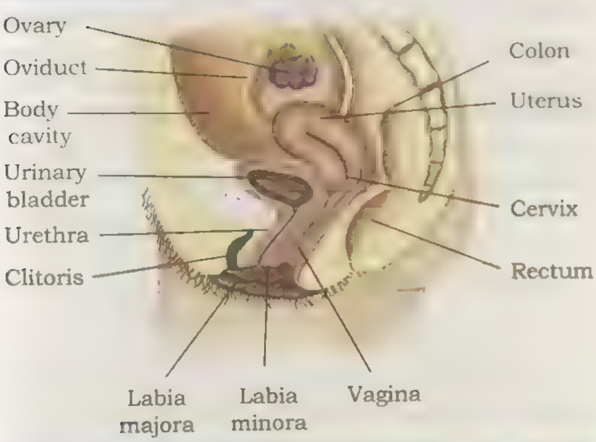


Fig. 14.9 *Human female reproductive system*

Each ovary is a compact or solid organ, consisting of an outer **cortex** and an inner **medulla** (Fig. 14.10). The stroma of the cortical region is composed of spindle-shaped fibroblasts. A poorly delineated dense connective tissue layer, the **tunica albuginea,** covers the cortex; it imparts the whitish colour to the ovary. Located outside the tunica albuginea, the **germinal epithelium**, formed of simple squamous or cuboidal epithelial cells, covers the surface of the ovary.

The female gametes, **eggs** or **ova**, in various stages of maturation, remain enclosed in the

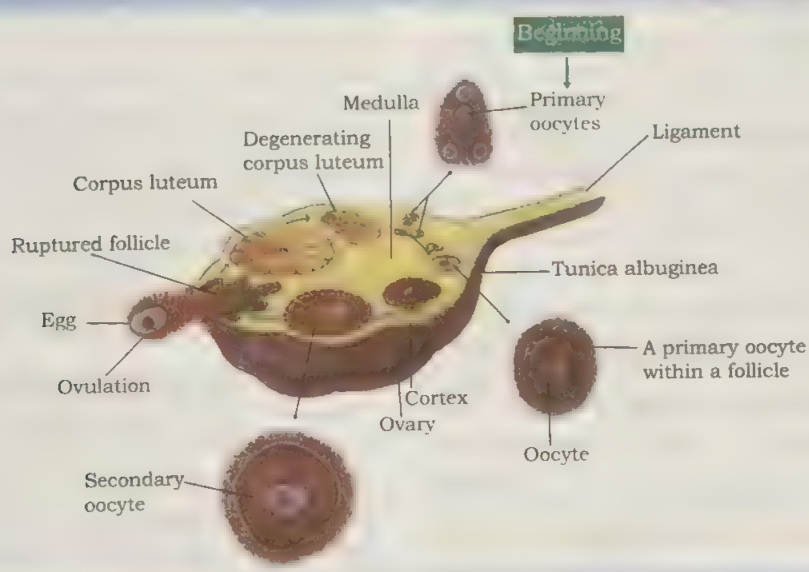


Fig. 14.10 *Sectional view of human ovary showing oocytes at various stages of development in the ovarian follicles*

scattered ovarian follicles that are embedded in the stroma of the cortex. A **follicle** consists of an oocyte surrounded by one or more layers of follicular cells, the **granulosa cells**, which are derived from the germinal epithelium. Each follicle gradually assumes a definite shape and structure. Although follicular growth involves the primary oocyte and the stroma surrounding the follicle, it is mainly the proliferation of follicular cells that counts. Follicular cells divide by mitosis and form a stratified follicular epithelium, the **granulosa layer**. A thick coat, the **zona pellucida**, composed of glycoproteins and synthesised by both the follicle cells and the oocyte, surrounds the oocyte. The mature follicle, the **Graafian follicle**, is about 2.5 cm in diameter. Due to accumulation of fluid, the follicular cavity increases in size and a fluid-filled eccentric cavity, the **antrum**, develops. The fluid of the antrum is termed as **liquor folliculi**. The maturing oocyte adheres to the wall of the follicle through a pedicel, the **cumulus oophorus**, formed by granulosa cells and, thus, remains suspended in the liquor folliculi. Later, the granulosa cells lying in close vicinity of the ovum and zona pellucida, become elongated to form the **corona radiata**. During **ovulation**, the mature follicle bursts and the ovum is released. After ovulation, the granulosa cells and the interstitial cells form a mass of large and yellowish conical cells. This is named as **corpus luteum** and serves as a temporary endocrine gland by releasing progesterone and estrogen. The total number of follicles in the two ovaries of a normal young adult woman is about four lakhs. However, most of them undergo regression and disappear due to death and disposal by phagocytes during the reproductive years of the females. This is referred to as **follicular atresia**. Generally, only one ovum is liberated in each menstrual cycle (average duration, 28 days) by alternate ovaries. Only about 450 ova are produced by a human female over the entire span of her reproductive life which lasts about 40-50 years of age. Although follicular cells and the oocytes undergo degeneration during follicular atresia, some thecal cells, formed from the stroma and located around the follicle, persist and become active. These are called **interstitial cells**; they secrete small amount of androgen.

Each ovary is located in front of a funnel-shaped opening of the uterus, the oviduct (fallopian tube). The **oviduct** is a muscular tube, measuring about 12 cm in length. Its lumen is lined by ciliated epithelium. The oviduct is situated above and behind the urinary bladder, and occupies the central position in the pelvic cavity. The wall of the oviduct is composed of three layers : a **mucosa** at the luminal surface, followed by a **muscularis**, and a **serosa** composed of visceral peritoneum. The mucosa consists of an epithelium that consists simple columnar cells that contain both ciliated cells and secretory cells. These secretory cells produce a viscous liquid film that provides nutrition and protection to the ovum. The oviduct of each side leads into the pear-shaped **uterus** that consists of a body or **corpus**, a narrow uterine cavity or the internal **os**, and a lower cylindrical structure, the **cervix**. The wall of the uterus is thick. Its luminar surface is lined by a mucous membrane, the **mucosa** or the **endometrium**, which consists of an inner **epithelium** and an outer connective tissue layer, the **lamina propria**. The epithelial cells are a mixture of ciliated and secretory simple columnar cells, whereas the connective tissue layer contains simple **tubular glands**, many fibroblasts and blood vessels. External to the mucosa, lies a thick tunic, the **myometrium**, which is composed of bundles of smooth muscles. The outermost invest of the uterus, depending on its part, is either the **serosa** (connective tissue or mesothelium) or the **adventitia** (connective tissue only).

The cervix projects slightly into an elastic muscular tube, the vagina. The wall of the **vagina** consists of a mucosa, a muscular layer and an adventitia; the vagina is devoid of glands. The vagina opens to the exterior by an aperture. The opening of the vagina remains partially covered by a thin ring of tissue, called the **hymen**. However, in the long run it is ruptured or destroyed due to vigorous physical activities. The **female external genitalia** or

vulva includes the **clitoris**, delicate lip-like skin folds, called **labia minora** and **labia majora**, and some glands that open in the vestibulum, a space enclosed by the labia minora. Anteriorly, two labia minora merge and form a very small structure, the clitoris, which is formed by two erectile bodies ending in a rudimentary **glans clitoridis** and a **prepuce**. The clitoris is covered with stratified squamous epithelium and is homologous to the male's glans penis.

The oviduct, uterus, vagina, clitoris, the accessory genital glands and mammary glands, constitute the **secondary sexual organs** of human female. Each mammary gland consists of 15-25 lobules of the compound tubuloalveolar type (Fig. 14.11).

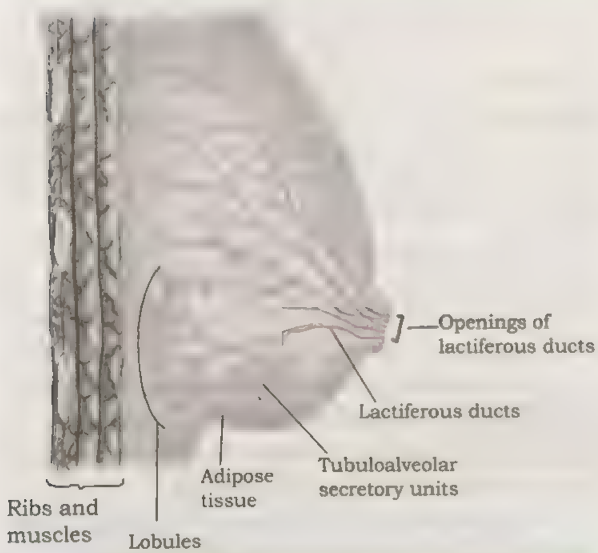


Fig. 14.11 *Human female mammary gland*

These lobules secrete milk to nourish the new-born babies. Each lobe is separated from the others by dense connective and adipose tissues and represents a gland. From each lobe, **excretory lactiferous ducts** emerge independently in the nipple, which has 15-25 openings, each about 0.5 mm in diameter. However, the histological structure of mammary glands varies, depending upon age and physiological state.

The human female reproductive system performs many functions : oogenesis (origin or production of eggs), reception of sperm during copulation, providing an environment conducive to fertilisation and supplying nutrition or nourishment to the baby, both at prenatal and postnatal stages. In this respect, the responsibility of the human female for successful reproduction is considerably greater than that of the male.

14.6 Events of Human Reproduction

The major events of human reproduction are formation of gametes, cyclic changes in the female body in preparation for receiving spermatozoa through coitus, fusion of gametes, development of the zygote and its gradual transformation into a tiny baby in the uterus of mother, production of milk for nourishment of the immature baby and, finally, the birth of the baby. All these events are regulated and coordinated by hormones secreted from the anterior pituitary gland and the gonads.

Formation of Gametes

Sexual reproduction requires the fusion of two haploid gametes to form a diploid individual. These haploid cells are produced through **gametogenesis**. As there are two types of gametes, the spermatozoa and ova, gametogenesis can be studied under two broad headings : spermatogenesis and oogenesis. **Spermatogenesis** is the formation of spermatozoa, whereas **oogenesis** is the formation of ova. Both spermatozoa and ova originate from **primordial germ cells (PGCs)**, which are extra-gonadal in origin. In humans, the PGCs originate during early embryonic development from the extra-embryonic mesoderm. Eventually, they migrate to the yolk sac endoderm, and ultimately, to the gonads of the developing embryo, where they undergo further development. You can recall that spermatogenesis occurs in the seminiferous tubules of the testes and oogenesis occurs in the follicles of ovary. Formation of gametes

starts at puberty, that starts at the age of 9-11 in girls and 11-13 in boys.

Spermatogenesis

Spermatogenesis (Fig. 14.12) is completed in three major steps. These are : (a) **spermatocytogenesis**, during which spermatogonia divide and produce successive generations of cells that give rise to **spermatocytes**, (b) **meiosis**, during which the spermatocytes go through one reduction division (meiosis I) and one equational division (meiosis II), and (c) **spermiogenesis**, during which the spermatids differentiate into spermatozoa. The **spermatogonial cells** are small cells, 12 μm in diameter. At sexual maturity, these cells divide several times by mitosis to produce a large number of spermatogonia. Some of them continue as stem cells or **type A spermatogonia** (*Gk. sperma*, seeds; *gonos*, generation). Others differentiate into progenitor cells or **type B spermatogonia**. Type A spermatogonia serve as the stem cells for spermatogenic lineage, whereas type B spermatogonia are the precursors of sperm and differentiate into primary spermatocytes. These type B spermatogonia undergo changes by accumulating nourishing materials obtained from the germinal cells; they become almost double in volume. This growth requires synthetic activities that are preparatory for initiation of meiosis. Such cells are called **primary spermatocytes**. The primary spermatocyte is larger and diploid or 2N; they possess 44 + XY (total 46) chromosomes. Soon, they enter the prophase of the first meiotic division and pass through the stages of prophase, such as leptotene, zygotene, pachytene, diplotene and diakinesis. Prophase is followed by metaphase, anaphase and telophase to complete the reduction division (meiosis I). The daughter cells produced at the end of meiosis I are smaller and termed as **secondary spermatocytes**; they are haploid or 1N and contain 22 + X or 22 + Y (total 23) chromosomes and 1N of DNA. The secondary spermatocytes undertake the meiosis II and produce the spermatids. In this way, from each of the type B spermatogonium altogether 4 haploid **spermatids** are produced.

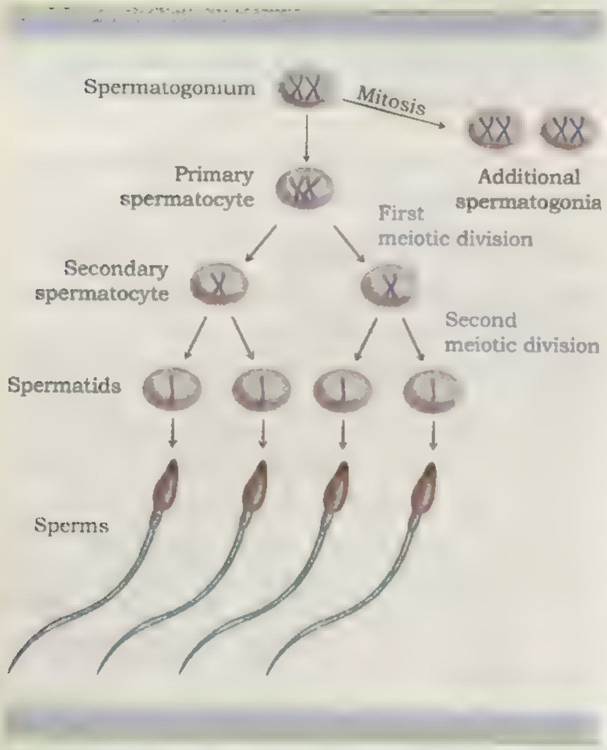


Fig. 14.12 *Spermatogenesis*

Each spermatid then differentiates into a mature spermatozoan by the process of spermiogenesis. This includes the formation of acrosome, condensation and elongation of the nucleus, development of the flagellum and the loss of redundant substances of the cytoplasm and its organelles. Ultimately, each spermatid transforms into a spermatozoan.

Sperm cells are little more than flagellated nuclei. Each consists of a **head** with an **acrosome** at its tip, a **midpiece** and a **tail** (Fig. 14.7). The head contains the nucleus having a haploid set of chromosomes in a compact and inactive state. The head is followed by the midpiece, which contains the mitochondria. A short neck that houses the proximal and distal centrioles connects the head and midpiece. The midpiece extends into the tail, which is reinforced by an axoneme formed of microtubules. An adult male manufactures over 10^{12} to 10^{13} sperm cells each day. These gradually move into the epididymis and the first

portion of the vas deferens, where they undergo further maturation and are stored.

Endocrine hormones control spermatogenesis (Fig. 14.13). **Interstitial cells** or **Leydig cells** that lie between the seminiferous tubules secrete **testosterone**, which is essential for making sperm. Interstitial cells are, in turn, the targets for a hormone called **interstitial cell stimulating hormone** (ICSH). It is a product of the anterior lobe of the pituitary gland and identical to the hypophyseal gonadotropins, **lutenising hormone** (LH) and **follicle-stimulating hormone** (FSH). Under the control of FSH and testosterone, Sertoli cells secrete an **androgen-binding protein** (ABP) that concentrates testosterone in the seminiferous tubules. Sertoli cells also secrete another protein, called **inhibin**, which suppresses FSH synthesis. FSH acts directly on spermatogonia to stimulate sperm production (aided by the LH needed for testosterone synthesis). Release of LH or ICSH is, in turn, controlled by the release of hypothalamic **gonadotropin releasing**

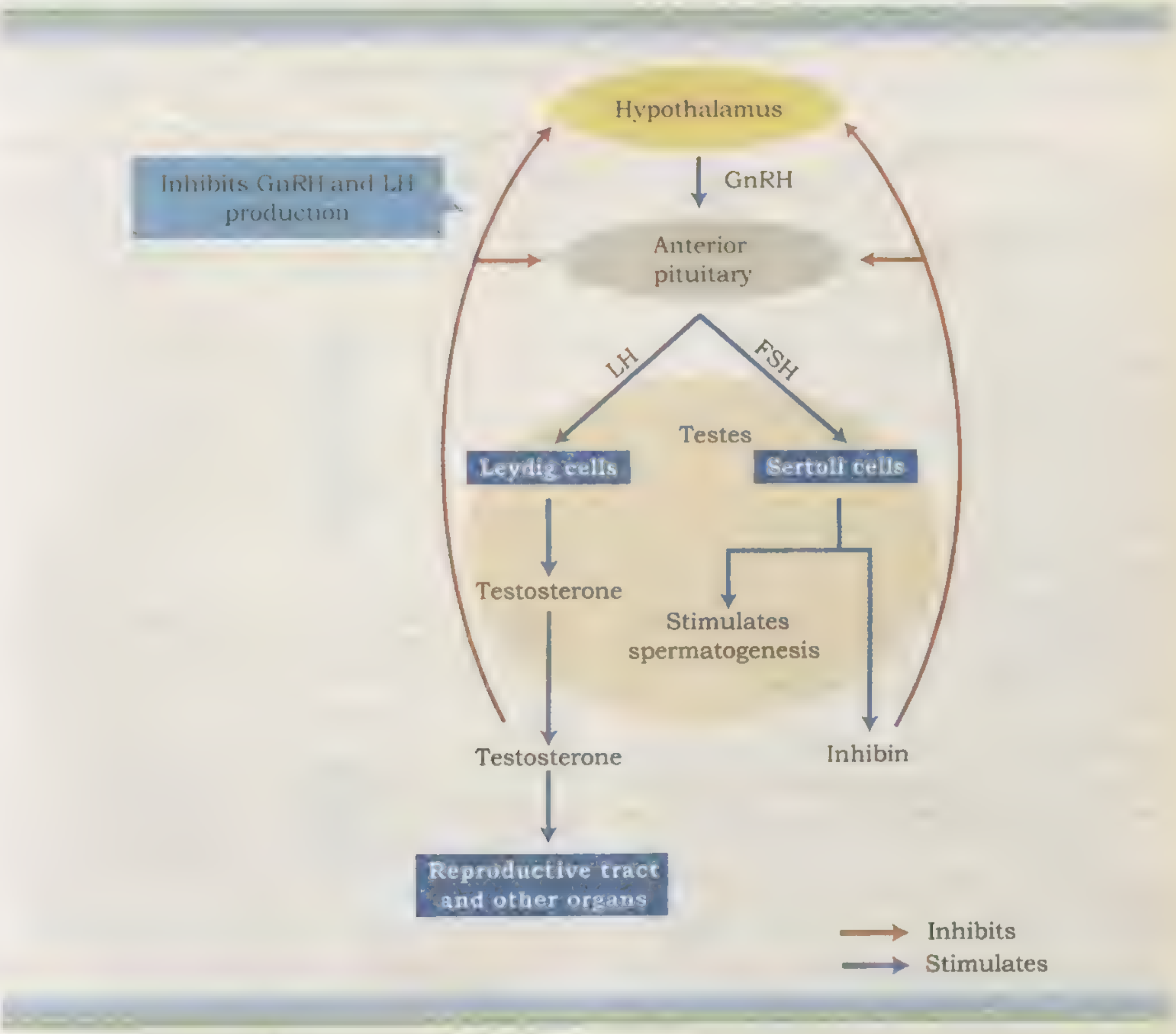


Fig. 14.13 *Hormonal control of male reproductive system*

hormone or **GnRH**. The level of testosterone is under negative-feedback control; a rising level of testosterone suppresses the release of GnRH from the hypothalamus.

Oogenesis

Oogenesis (Fig. 14.14) takes place in the ovaries. In contrast to males, the initial steps

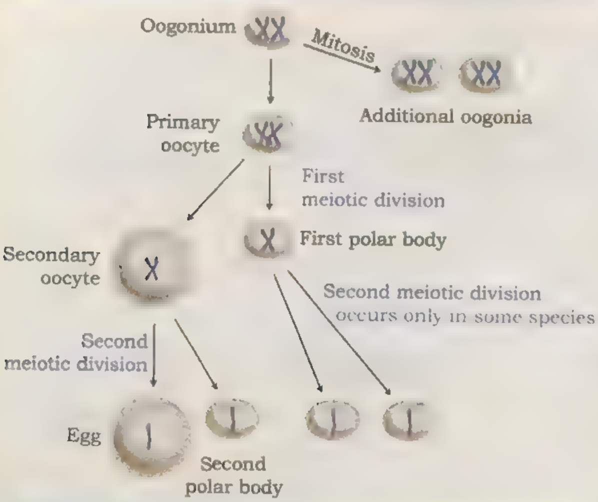


Fig. 14.14 *Oogenesis*

in egg production occur prior to birth. By the time the foetus is 25 weeks old, all the oogonia that she will ever produce, are already formed by mitosis. Hundreds of these cells (about 45,000-65,000) develop into **primary oocytes**, begin the first steps of the first meiotic division, proceed up to diakinesis, and then stop any further development. The oocytes resume their development when the female matures sexually, i.e., attains puberty. The oocytes start developing, usually one at a time and once a month. The primary oocyte grows much larger and completes the meiosis I, forming a large **secondary oocyte** and a small **polar body** that receives very little amount of cytoplasm but one full set of chromosomes.

In humans (and most vertebrates), the first polar body does not undergo meiosis II, whereas the secondary oocyte proceeds as far as the **metaphase** stage of meiosis II. However, it then stops advancing any further; it awaits the arrival of the spermatozoa for completion of second meiotic division. Entry of the sperm restarts the cell cycle breaking down **MPF** (M-phase promoting factor) and turning on the **APC** (Anaphase promoting complex). Completion of meiosis II converts the secondary oocyte into a fertilised egg or zygote (and also a second polar body).

Oogenesis occurs under the influence of **endocrine hormones** (Fig. 14.15). The human

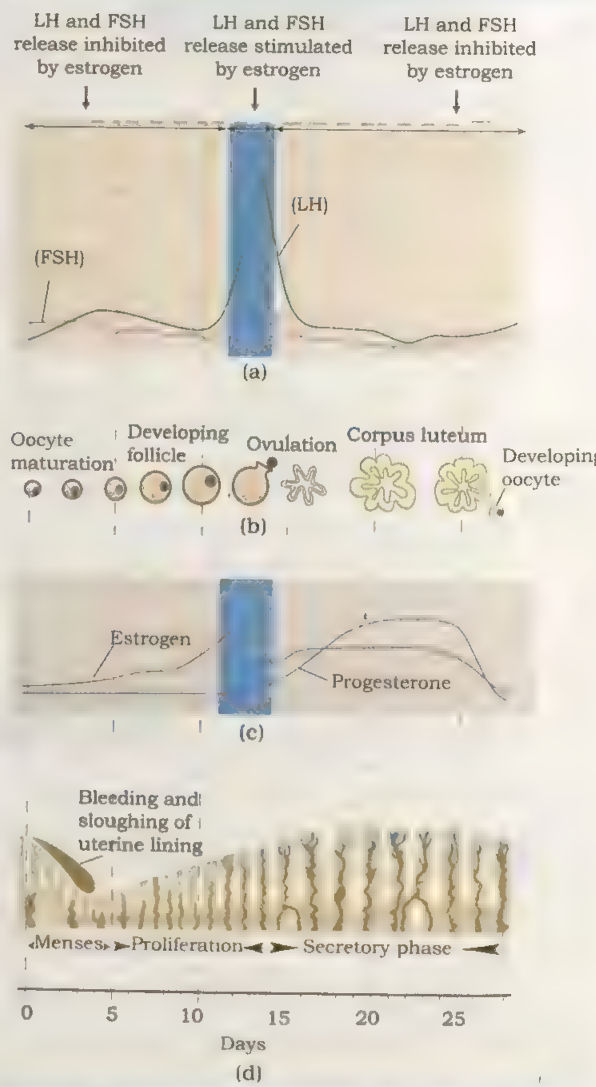


Fig. 14.15 *Menstrual cycle showing hormonal relations : (a) Gonadotropin, (b) Ovarian cycle, (c) Ovarian hormones, (d) Uterine cycle*

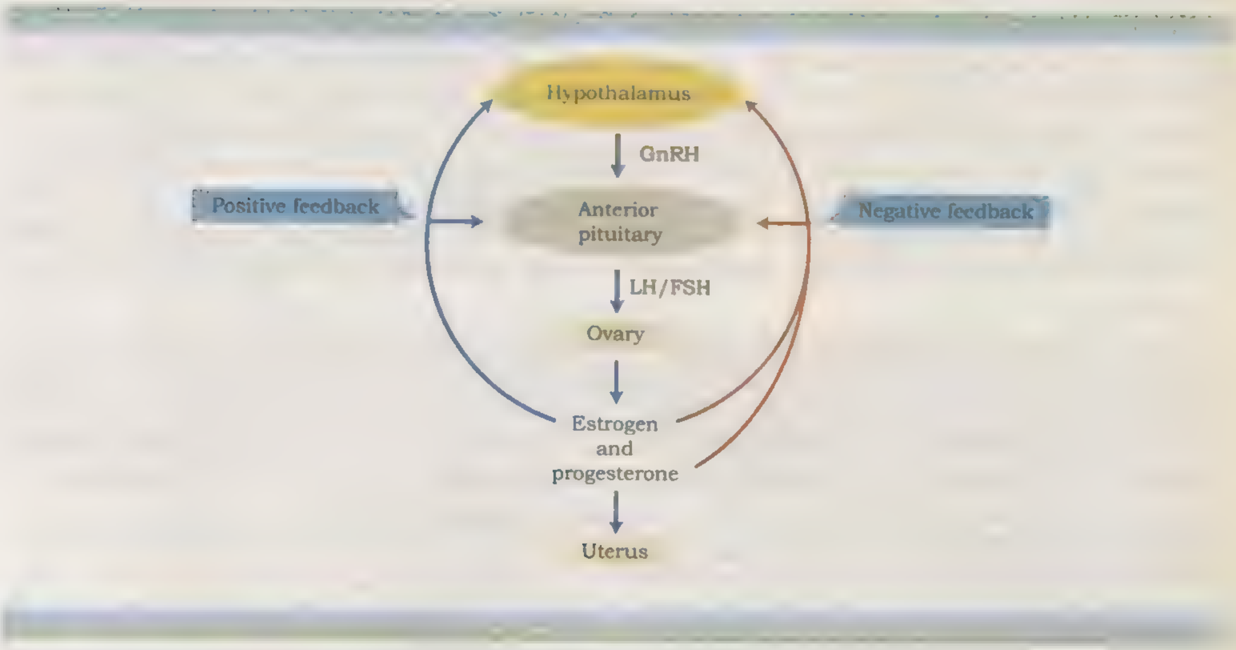


Fig. 14.16 Hormonal control of female reproductive system

female produces ova at more or less regular intervals within their ovarian follicles. The mature follicle ruptures to liberate the ovum. This is called **ovulation**. Ovulation takes place in approximately the middle of the menstrual cycle. The stimulus is a surge of **lutenising hormone** (LH) secreted by the anterior pituitary gland. The granulosa cells of developing ovarian follicles synthesise **estrogens**, whereas the corpus luteum synthesises both estrogens and **progesterone**. Estrogens are a group of steroids and are responsible for the development of the secondary sexual characteristics of a mature woman. The synthesis and secretion of estrogens is stimulated by hypophyseal gonadotropin, **follicle stimulating hormone** (FSH), which in turn, is controlled by the hypothalamic **gonadotropin releasing hormone** (GnRH). High levels of estrogens suppress the release of GnRH, providing a negative-feedback control of hormone levels. This is exactly parallel to the control of testosterone in males.

Progesterone is also a steroid. It has many effects in the body. Progesterone production is stimulated by hypophyseal gonadotropin, lutenising hormone (LH), which is also stimulated by hypothalamic GnRH. Elevated levels of progesterone also control themselves by a negative feedback loop with progesterone inhibiting the further release of GnRH.

Estrogens continue to be secreted throughout the reproductive years of women. During this period, the reproductive system of women shows regular cyclic changes. The cycle is known as **menstrual cycle** (Figs. 14.16 and 14.17). Menstrual cycles start between 11

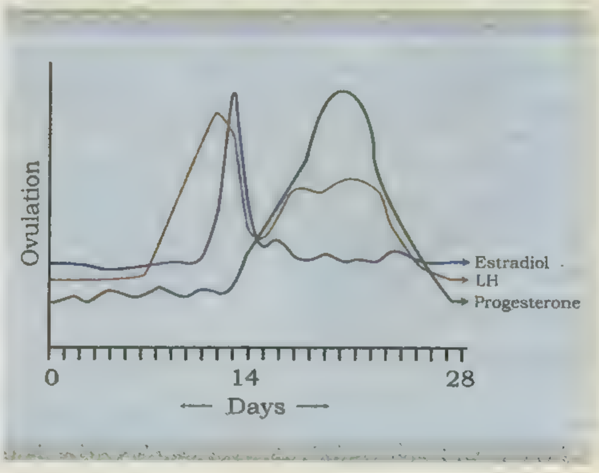


Fig. 14.17 Graphical representation of menstrual cycle

and 15 years of age and continue until about 45-50. On an average, menstrual cycles continue for 28 days, after which some blood and other products of the disintegration of the uterine mucosa (the endometrium) are sloughed off and discharged from the uterus as menstrual bleeding. The process is called **menstruation**. Estrogen plays a central role in the menstrual cycles.

As the menstruation ceases, the ovarian follicles begin to develop, secreting an increasing amount of **estrogens**. The rising level of estrogens causes the endometrium to become thicker and more richly supplied with blood vessels and endometrial glands. A rising level of **FSH** stimulates the growth of the ovarian follicles and the formation of estrogens. The most immediate effect of FSH is the maturation of existing late primary or secondary follicle. A rising level of FSH causes the developing egg within the follicle to complete the first meiotic division to form a **secondary oocyte**. Stimulated by LH, the corpus luteum secretes **progesterone**, which facilitates the preparation of the endometrium for receiving the blastocyst and its implantation. Progesterone inhibits the contraction of the uterus and the development of a new follicle. In the absence of fertilisation, the rising level of progesterone inhibits the release of GnRH, which, in turn, inhibits production of FSH, LH and progesterone. As the progesterone level drops, the corpus luteum begins to degenerate and transforms into a white body, the **corpus albicans**. Consequently, the endometrium begins to break down, the inhibition of uterine contraction ceases and the bleeding and cramps of menstruation begin.

Fertilisation

Fertilisation is the union of two opposite types of gametes, spermatozoa and ova. The semen is a mixture of spermatozoa and accessory fluids. Once deposited within the vagina, the spermatozoa proceed on their journey into and through the uterus and on up into the oviducts. Although spermatozoa can swim several millimeters each second, their trip through the uterus and to the oviducts requires an increase in their motility. On the first hand, ejaculation of semen in the vagina triggers motility of spermatozoa. This is aided further by muscular contraction of the walls of the uterus and the oviducts. An additional increase in sperm motility occurs due to activation of the sperm by the viscous liquid secreted from the secretory cells of the epithelial lining of oviductal mucosa. This phenomenon of sperm activation in mammals is known **capacitation**. It takes about 5-6 hours for capacitation.

Before fusion of a spermatozoan with the egg, the spermatozoa are to penetrate a few barriers, the **egg membranes**, which cover the egg. The activated spermatozoa undergo **acrosomal reaction** and release various chemicals, like **hyaluronidase** that acts on the **ground substances** of follicle cells, **corona penetrating enzyme** that dissolves **corona radiata**, and **zona lysine** or **acrosin** that help to digest the **zona pellucida**. All these chemicals are contained in the acrosome, located at the tip of the sperm head, and are collectively termed **sperm lysins**. **Fertilin** proteins are present on sperm surface. An average human ejaculate of 3-4 ml of semen contains 80-100 million spermatozoa. Out of these, only one will succeed in entering the egg and fertilising it. Fertilisation of egg with only one spermatozoan is known as **monospermy**. Several physical and chemical events take place in response to egg-sperm binding. First, the egg becomes activated and undergoes **depolarisation** of its membrane. Second, the egg exhibits **cortical reaction** and shows zona reaction, which makes the egg impervious to any second sperm. This is how **polyspermy**, the entry of more than one sperm into the ovum, is prevented from taking place. It should be remembered that prior to fertilisation, the oocyte is released from the ovary and swept into the oviduct and fertilisation occurs in the ampulla of the oviduct, a region close to the

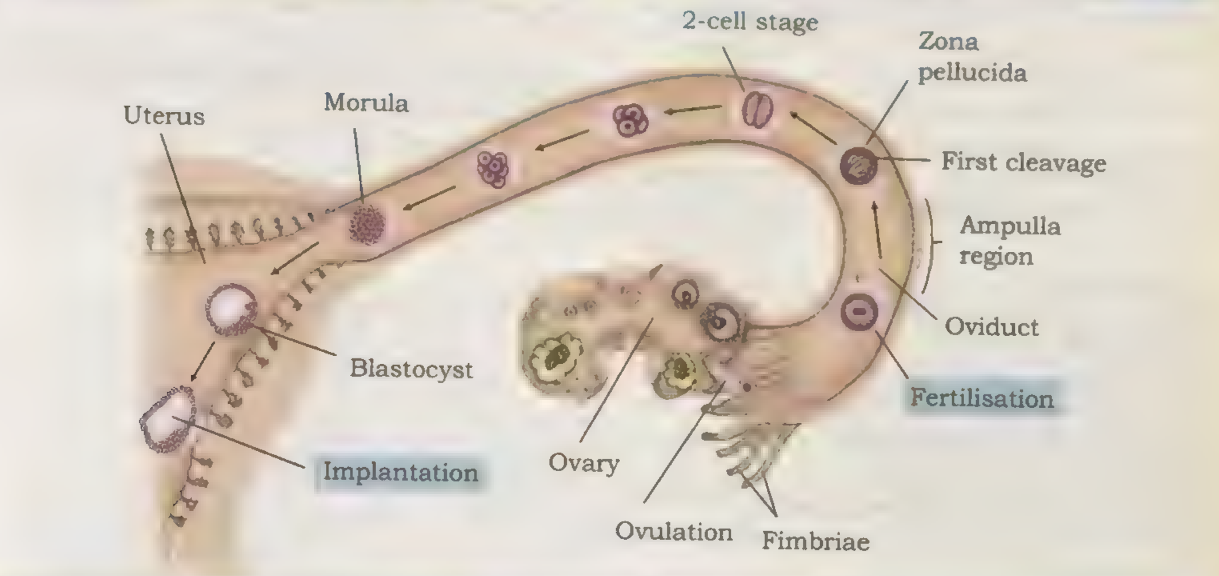


Fig. 14.18 *Development of human embryo in female reproductive tract (Fertilisation–implantation)*

ovary (Fig. 14. 18). However, soon the head of the successful sperm enlarges into the **male pronucleus**. At the same time, the egg (secondary oocyte) completes meiosis II, forming a **second polar body** and the **female pronucleus**. The male and female pronuclei move toward each other. Their nuclear envelopes disintegrate. A spindle is formed, and a full diploid set of chromosomes, one paternal set and one maternal set, assembles on it. The fertilised egg or **zygote** is now ready for its first mitosis to initiate the first phase of embryonic development, the **cleavage**.

Embryonic Development

Ordinarily, cleavage divisions occur in quick succession without any intermittent growth or synthetic phase; they are rapid, rhythmic and repeated mitotic divisions. In mammals, including humans, cleavage divisions are among the slowest in the animal kingdom. Also, the cleavage divisions are asynchronous from the very beginning; the number of resultant cells increase, following arithmetic progression. Cleavage divisions result in complete division of the zygote and the subsequent daughter cells, the **blastomeres** (Figs. 14.19 and 14.20). Such type of cleavage

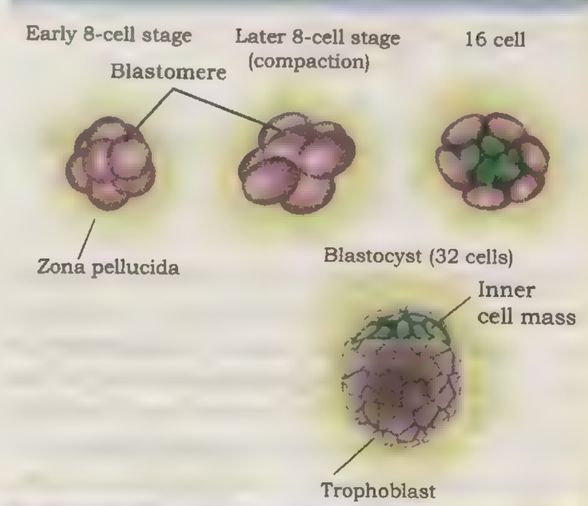


Fig. 14.19 *Stages of formation of blastocyst in a mammal*

is known as **holoblastic** cleavage. The embryo at the 16-celled stage is called the **morula**. The term 'morula' has its basis on the resemblance of this developmental stage with a mulberry fruit. The morula passes through the phase of **compaction**, produces two major types of cells : the **peripheral cells** and the **inner cell mass**. The descendants of peripheral cells become the **trophoblast (trophectoderm)** cells. This group of cells later produce the four extraembryonic membranes and part of the placenta. The embryo proper develops from the inner cell mass in course of further development. The trophoblast cells secrete fluid into the morula to form the blastocoel. The resulting structure is called the **blastocyst** (Figs. 14.19 and 14.20). Approximately one week after

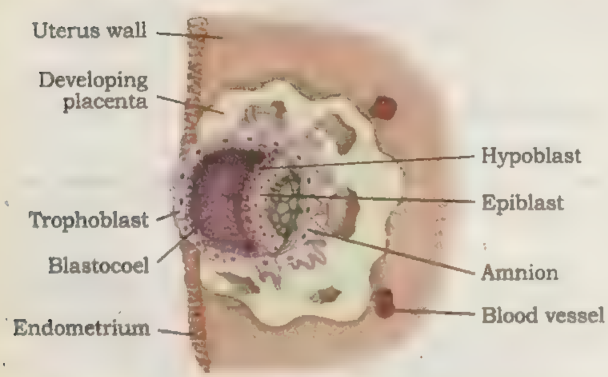


Fig. 14.20 *A human blastocyst*

fertilisation, the blastocyst embeds itself in the thickened wall of the uterus, a process called **implantation**, and **pregnancy** is established. After implantation, the uterine mucosa (endometrium) undergoes profound changes and is called the **decidua**. The decidua tissues can be distinguished into **decidua basalis**, situated between the embryo and uterine serosa (myometrium); **decidua capsularis**, between the embryo and the lumen of the uterus; and **decidua parietalis**, the remaining part of the deciduas (Fig. 14.21).

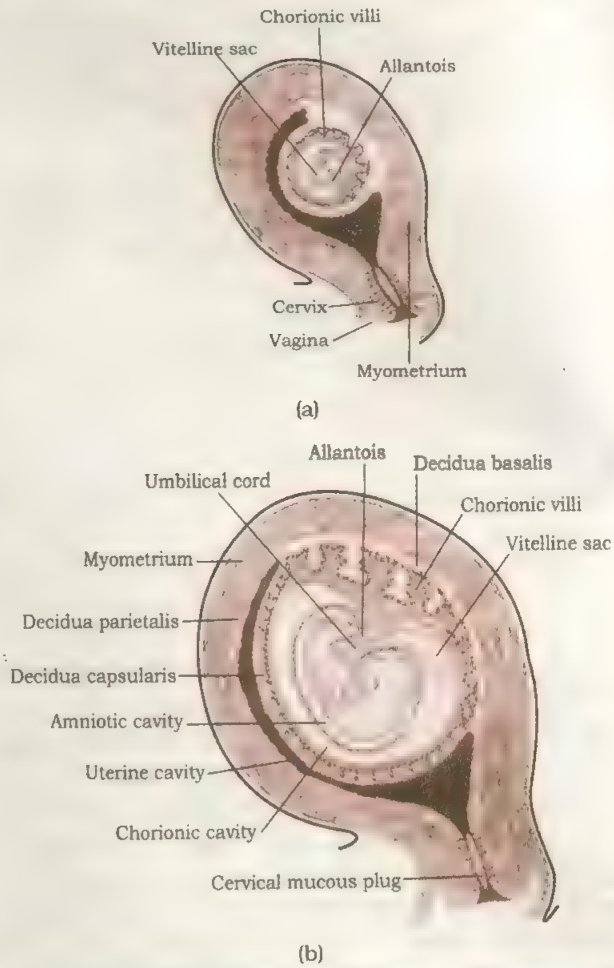


Fig. 14.21 *Three regions of decidua (a) early stage, (b) late stage*

The blastocyst then undergoes **gastrulation** to produce the three primary germinal layers. This involves cell movements that eventually help to attain new shape and morphology of the embryo. These cell movements are called **morphogenetic movements**. Following gastrulation, the embryo passes through the phase of **neurulation**, during which the primordium of nervous system, the **neural plate**, is laid down. Gradually, the organ rudiments appear and

the process of **organogenesis** is inaugurated. During organogenesis, the various organs of the foetus are established and they attain functional state.

The extraembryonic or foetal membranes are the **amnion**, **chorion**, **allantois** and **yolk sac**. Amnion provides a fluid medium to the developing embryo; it prevents desiccation of the embryo and function as a shock absorber. As the human egg is devoid of yolk, the yolk sac develops as an evolutionary process. It is very small and gradually degenerates and shrinks. The chorion and allantois take part in the formation of placenta. The human placenta is, thus, referred to as **chorioallantoic placenta**. The **placenta** is a temporary association between the foetal and maternal tissues. It consists of foetal part, the chorion, and a maternal part, the decidua basalis. The foetal placenta grows intimacy and invades the uterine mucosa with its **chorionic villi**. The degree of intimacy is so strong that eventually the blood vessels of the villi are literally bathed in the mother's blood. This becomes possible due to erosion of the uterine mucosa, including its epithelium, connective tissue and the endothelial lining. This type of placenta is known as **haemochorial placenta**. Placenta acts as a barrier between the foetus and the mother. Although there is no blending of the two blood supplies, the placenta acts as an ultrafilter; soluble inorganic and organic materials nutrients, hormones, antibodies against diphtheria, small pox, scarlet fever, measles, etc. can pass from the mother to the foetus. It also helps in the exchange of gases between the mother and the foetus. The placenta also helps in the elimination of nitrogenous discharge and other wastes of the foetus. Placenta acts as an endocrine gland and synthesises large quantities of proteins and some hormones, such as human chorionic gonadotropin (HCG), chorionic thyrotropin, chorionic corticotropin, chorionic somatomammotropin, estrogens and progesterone. The HCG stimulates the **corpus luteum of pregnancy** that continues to secrete progesterone until the end of pregnancy. In addition, it secretes **relaxin** that facilitates parturition by softening the connective tissue of the symphysis pubica. The metabolic activity of the placenta is almost as great as that of the foetus itself. The **umbilical cord** connects the foetus to the placenta.

During the first trimester (first 3 months) of **pregnancy**, the basic structure of the baby is formed. This involves cell division, cell migration, and the differentiation of cells into the many types found in the baby. During this period, the developing baby – called **foetus** – is very sensitive to anything that interferes with the steps involved. Virus infection of the mother, e.g., by rubella (German measles) virus or exposure to certain chemicals, may cause malformations in the developing embryo. Such agents are called **teratogens** (monster-forming). By 3 months, all the systems of the baby have been formed, at least in a rudimentary way. From then on, development of the foetus is primarily a matter of growth and minor structural modifications. The foetus is less susceptible to teratogens. Pregnancy involves a complex interplay of hormones. Progesterone is required continually during entire period of gestation or pregnancy. It is, therefore, called **pregnancy hormone**.

Exactly what brings about the onset of **labour** is termed **parturition**. Probably a variety of integrated hormonal controls are at work. The first result of labour is the opening of the cervix. With continued powerful contractions, the amnion ruptures and the amniotic fluid (the "waters") flows out through the vagina. The baby follows and its umbilical cord can be cut. Shortly after the baby is born, the placenta and the remains of the umbilical cord (the "afterbirth") are expelled. The infant's lungs expand and it begins breathing. This requires a major switchover in the circulatory system. Blood flow through the umbilical cord, ductus arteriosus and foramen ovale ceases; the adult pattern of blood flow through the heart, aorta and pulmonary arteries begins. In some infants, the switchover is incomplete, and blood flow through the pulmonary arteries is inadequate.

The first milk which comes out from the mother's mammary glands just after child birth is known as **colostrum**. It is rich in proteins and energy. Also, it contains antibodies that provide passive immunity for the newborn infant. Three or four days after delivery, the breasts begin to secrete milk. Its synthesis is stimulated by the pituitary hormone **prolactin** (PRL). Its release is stimulated by a rise in the level of **oxytocin** when the baby begins nursing. Milk contains an **inhibitory peptide**. If the breasts are not fully emptied, the peptide accumulates and inhibits milk production. This autocrine action, thus, matches supply with demand.

SUMMARY

Plants and animals reproduce by employing a wide range of mechanisms. But the basic types are asexual and sexual. In asexual reproduction a single parent is involved. In this method, a single-celled or many-celled parent individual either splits or buds or fragments into two identical daughter cells or individuals. There are three common modes of asexual reproduction : fission, budding and fragmentation.

In sexual reproduction, two parents, each capable of producing gametes, spermatozoa and ova, are required. In human beings, reproduction takes place by sexual method and the sexes are separate. The human male reproductive system is composed of a pair of testes, genital ducts, several accessory glands and penis. The female reproductive system consists of two ovaries, two oviducts (uterine tubes), the uterus, a vagina and the external genitalia, accessory genital glands and the mammary glands.

There are two types of gametes, the spermatozoa and ova. Spermatogenesis is process of the formation of spermatozoa, whereas oogenesis is the formation of ova. Formation of gametes starts at puberty that starts at the age of 9-11 in girls and 11-13 in boys. Fertilisation is the union of two opposite types of gametes, spermatozoa and ova. Intercourse or coitus accomplishes sperm transfer. The male and female pronuclei move toward each other. Their nuclear envelopes disintegrate. A spindle is formed, and a full diploid set of chromosomes, one paternal set and one maternal set, assembles on it.

Development is the emergence of a multicellular organism from a single group of cells. It involves growth, differentiation and morphogenesis. Growth is characterised by cell proliferation or secretion of extracellular materials. Differentiation means diversification of cell to attain their specific functions. Morphogenesis is the emergence of new pattern in the embryo. The fertilised egg or zygote is now ready for its first mitosis to initiate the first phase of embryonic development, the cleavage. Cleavage divisions result in complete division of the zygote and the subsequent daughter cells. The resulting structure is called the blastocyst. The blastocyst then undergoes gastrulation to produce the three primary germinal layers. This involves cell movements (morphogenetic movement) that eventually help to attain new shape and morphology of the embryo. By three months, all the systems of the baby are formed, at least in a rudimentary way. From then on,

development of the foetus, as it is now called, is primarily a matter of growth and minor structural modifications. At the time of birth and for a few days after, the mother's breasts contain a fluid called colostrum. It is rich in calories and protein. Also, it contains antibodies that provide passive immunity for the new-born infant. Three or four days after delivery, the breasts begin to secrete milk.

EXERCISES

1. What are the fundamental methods of reproduction?
2. Name two acellular protists which reproduce sexually.
3. What is fission? What is the basic difference between the fission in *Amoeba* and *Paramoecium*?
4. When are pseudopodiospores formed?
5. How are gemmules formed in marine sponges?
6. Define zygote.
7. What is conjugation?
8. Animals with self-fertilising ability are termed as ________.
9. Development of unfertilised ovum into a new individual is called ___________.
10. The mature follicles are termed as _________.
11. Degenerated corpus luteum is called _________.
12. What is sexual dimorphism?
13. Write down the major components of testis.
14. What is rete testis?
15. How does the inguinal hernia develop?
16. What is semen?
17. Name the accessory genital glands in male.
18. Where do you find corpora cavernosa?
19. What is mesovarium?
20. What is cumulus oophorus?
21. How is corpus luteum formed? What is its function?
22. What is follicular atresia?
23. Name the accessory structures of female reproductive system.
24. What is spermatogenesis? Write down its steps.
25. How do Leydig cells help in spermatogenesis?
26. Briefly describe the process of oogenesis.
27. What is menstrual cycle? Write down the hormonal control over the menstrual cycle.
28. What is capacitation?

29. Name some chemicals that are released by acrosome during fertilisation.
30. What is cortical reaction?
31. How is polyspermy prevented?
32. When do morphogenetic cell movements take place?
33. Name the type of extraembryonic membranes.
34. What is placenta? Give its functions?
35. What is teratogen?
36. How does parturition take place?
37. What is colostrum? How is milk production hormonally regulated?
38. Match the items in column I with those in column II :

	Column I		Column II
(i)	clone	(a)	sporulation
(ii)	liberation of spores	(b)	gamete mother cells
(iii)	inguinal canals	(c)	genetically identical offsprings
(iv)	clitoris	(d)	testicular lobules
(v)	primordial germ cells	(e)	oogenesis
(vi)	type A spermatogonia	(f)	connection of scrotum with abdomen
(vii)	seminiferous tubules	(g)	complete division of zygote
(viii)	polar body	(h)	spermatogenic lineage
(ix)	holoblastic cleavage	(i)	rudimentary erectile body
		(j)	meiotic division during spermatogenesis

Chapter 15

Growth, Regeneration and Ageing

As revealed in the earlier chapter, during embryonic development, the fertilised ovum or zygote divides by mitosis and forms a single group of cells. This group of cells undergoes systematic changes and eventually is transformed into tiny individual. The occurrence of cell proliferation signifies that embryonic development is featured by growth. Growth usually involves cell proliferation. The other characteristics of development are morphogenesis that brings forth new form by cell movements, and differentiation that produces increased diversity of cells. As these two aspects are outside the arena of this chapter, we will restrict our discussion on growth only. Considerable growth occurs during late embryonic or foetal period of mammals. Still, development does not stop at birth, or even at the adulthood. During post-embryonic development, an embryo gradually grows into an adult. Each day the adult humans continuously peel off and replace more than a gram of skin cells, generate millions of erythrocytes and renew the digestive tract epithelium from stem cells. Besides these continuous daily changes, there are many instances of development in adult life. **Metamorphosis** (the transition from a larval stage to an adult stage) also involves development (post-embryonic). The third category of post-embryonic development is **regeneration**, creation of new organ after the original one has been removed. Interestingly, all such post-embryonic developments are also characterised by growth, morphogenesis and differentiation. Finally, post-embryonic development also involves changes in the adult that encompasses alterations of form associated with **ageing**. In this chapter, you will be acquainted with various aspects of embryonic and post-embryonic growth. Also, the intricacies of cellular growth will find place in this description. After that, thrust will be given on the general aspects of regeneration. At the end, a discussion on the nature and causes of ageing are included in this chapter.

15.1 Growth

Growth is defined as an irreversible increase in the mass or overall size of a tissue or an organism. This increase in body size of a growing animal involves some concurrent changes in their cells, tissues and organs. Growth is accomplished by three strategies. These are cell proliferation, or cell enlargement without division, or secretion of large amount of extracellular materials (Fig. 15.1). To cite examples : lens cells grow by multiplication; cardiac and skeletal muscle cells grow by increase in volume; neurons grow by extension and growth of the axons and dendrites; cartilage and bone cells grow by secretion of extra-cellular matrix. Generally, growth involves synthesis of protoplasm (nucleus and cytoplasm) or apoplasmic substances (matrix of the bone marrow, or fibres of the connective tissue or even water). Growth occurs when the synthetic activities (anabolism) of cells exceed their destructive activities (catabolism). There will be no growth if the synthesis equals destruction. Prolonged starvation may lead to increased catabolism of reserve food (e.g., fat

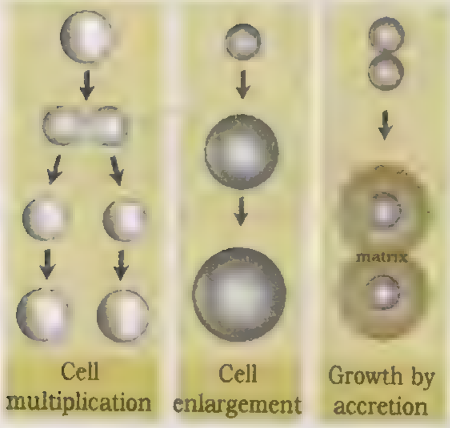


Fig. 15.1 *Strategies of growth*

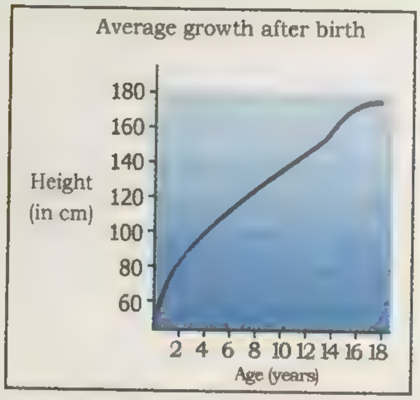
in the adipose tissue). In extreme situation, destruction of the constituent proteins of the protoplasm, leading to decrease in the mass of living matter, may be observed. This is opposed to growth and, thus, may be called **degrowth**. However, growth is the central aspect of all developing systems.

Embryonic Growth

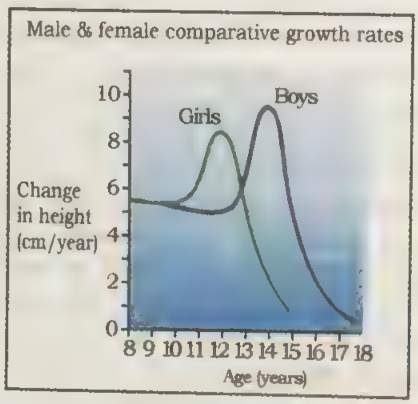
In early embryonic development, the cells produced during cleavage and blastula formation get smaller and smaller at each cleavage division. These cells exhibit little growth. During gastrulation, the primary organ rudiments of the embryo are laid down and the basic morphological plan is established. However, such organ rudiments are too small and are incapable of performing specific functions; they remain in the prefunctional state. With further advancement of development, these prefunctional organ rudiments grow, differentiate and attain functional state. The distinct cell types produced by the process of differentiation exhibit growth. To be precise, how much an organism or an organ grows (growth programme) is specified at an early stage of development. Overall growth of the organism mainly occurs in the period after the basic morphological plan is established.

Post-embryonic Growth

All higher animals grow at a specific rate and rhythm. But the rate of growth is not uniform. Animals grow at different rates at different periods of life. Human growth provides a good model for growth. The human embryo is about 150 µm at the time of implantation. It grows to about 50 cm over the nine months of gestation. During the first two months after implantation, the basic human body plan is laid down, but the embryo does not grow considerably. Starting from about 4 months of implantation, the embryo grows at the rate of 10 cm per month. During the first year after birth, growth occurs at a rate of 2 cm per month. The growth rate, then declines steadily; it then shoots at puberty (Fig. 15.2). After completion



(a)



(b)

Fig. 15.2 *Growth pattern in humans : (a) Average growth, (b) Comparative growth of boys and girls*

of puberty, the physical growth of human body starts declining; it almost stops after 22-23 years of age.

Also, the growth of different parts of the body varies; different organs grow at different rates (Fig. 15.3). At 9 weeks of development, the head of a human embryo is more than a third of the length of the whole embryo; it becomes about one-fourth. After birth, the rest of the body parts grow at a faster rate. In the adult, the head is about one-eighth of the whole body.

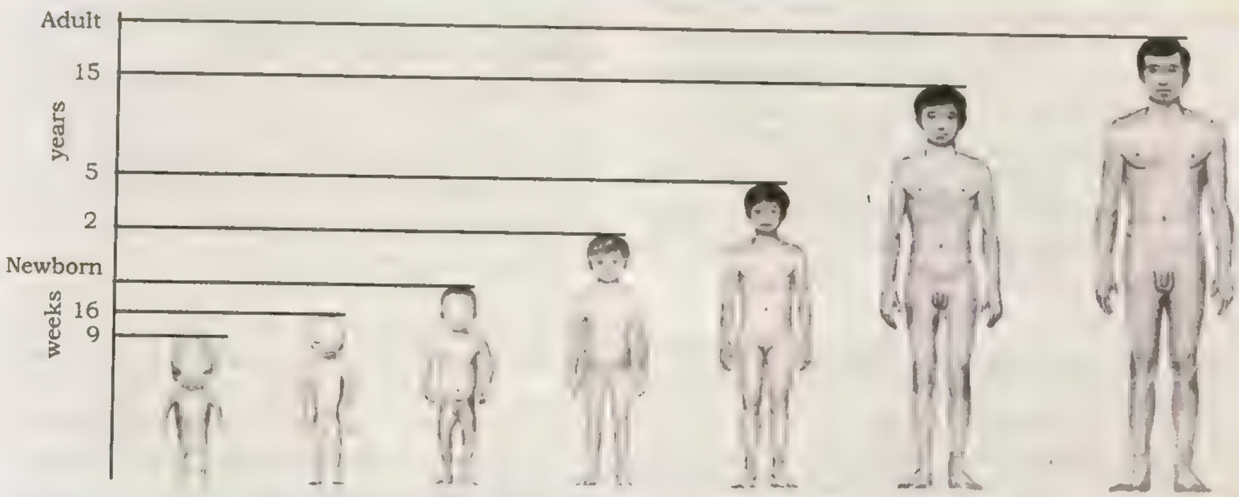


Fig. 15.3 *Human body parts grow at different rates*

Cellular Growth

The growth of multicellular organisms is based on the activities of individual cells that constitute the body. Such cellular growth involves reproduction (division) and growth (increase in volume) of cells. You are familiar with the types of cell divisions. When a eukaryotic cell duplicates (divides) itself, it follows a fixed sequence of events called **cell cycle**. The cell grows in size, the chromosomes and DNA replicate, and the cytoplasm is almost doubled in preparation for cell division. You are familiar with how cells divide with the unique precision following the cycle of phases $\mathbf{G_1}$, **S**, and $\mathbf{G_2}$ and **M**. Synthesis of new DNA and proteins during the interphase results in the growth of cells. Growth of individual cells is the most essential component of the growth of multicellular bodies. Unfortunately, because of the small size of cells, measuring the growth of individual tissue cells is very difficult. However, actual measurements of growth of single cells between two mitoses have been made on unicellular organisms. This can also be achieved by tissue culture.

Types of Growth

It is possible to relate the growth of the organism with the growth of their cells. Thus, three basic types of cellular growth can be identified. These are auxetic growth, multiplicative growth and accretionary growth. In **auxetic growth**, the volume of the individual increases due to growth of the individual cells; no division or proliferation of cells occurs. Such growth is observed among the rotifers, nematodes and some tunicates. In **multiplicative growth**, mitotic proliferation of the constituent cells leading to increase in

number is a must. It is typically found in the embryonic growth of animals. In **accretionary growth**, the growth of the animal is based on the activity of special cells. In the post-embryonic life, majority of cells are differentiated and perform specific functions. Yet, some cells of the adults remain in the undifferentiated state and retain the ability to divide mitotically. These cells are called **reserve cells**, and supply new cells for reinforcing and replacing the incapacitated differentiated cells. For example, the erythrocytes are differentiated non-dividing cells, and the proliferating erythropoietic tissues constantly supply new erythrocytes. Secretion of extracellular matrix by chondrocytes and bone osteocytes, which do not divide, serve other examples of accretionary growth.

Growth Curve

Under nutritionally non-limiting conditions, each animal attains the definite mature size very well. Although increase in mass often accompanies increase in length or height (linear dimensions), only weight is considered as an index of growth. Weight of an animal, taken at regular interval, if plotted against time on a diagram, a curve is obtained. This curve resembles the shape of **S** and is called **growth curve** (Fig. 15.4). In the initial part, the curve rises gradually, in the middle part, the curve rises steeply and in the last part, the curve rises slowly, and then approaches a horizontal line signifying the limit of growth in each particular case. A curve of this shape is known as sigmoid curve. The difference between the initial and final weight or size of an individual in a given period of time is regarded as the absolute increase. This growth curve characterises the growth of all higher animals and human.

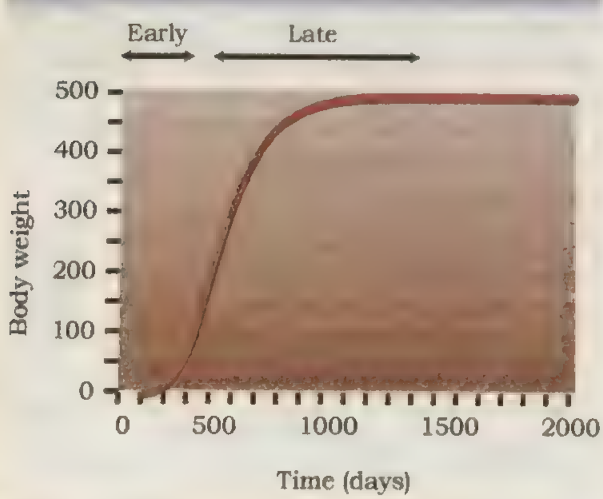


Fig. 15.4 Growth curve of a 500-kg animal

Hormonal Control of Growth

Embryonic growth depends on growth factors. For example, fibroblast growth factors (FGFs) control cell proliferation in the development of limbs in chick; insulin-like growth factors (IGFs) play a key role in both embryonic and post-embryonic growth of mammals. Growth hormone (GH) is produced in the pituitary gland and plays a critical part in normal childhood growth and post-embryonic growth of humans and other mammals. Within the first year after birth, secretion of growth hormone by the pituitary gland begins. Hypothalamus produces and releases both growth hormone-releasing hormone and somatostatin. Growth hormone-releasing hormone promotes growth hormone synthesis and secretion, while somatostatin inhibits its production and release. Growth hormone also controls its own release by negative feedback signals to the hypothalamus. It works by stimulating the production of IGF, which comes mainly from the liver and, in turn, promotes the synthesis of growth hormone. Studies reveal that cells must receive signals through growth factors or other proteins for division and survival. In the absence of required signal, internal death programme is activated and the cells commit suicide by apoptosis. Growth rate of a growing tissue depends on the rates of both cell proliferation and cell death.

15.2 Regeneration

As stated earlier, our body spontaneously loses cells from the surface layer of the skin and the inner lining of intestine. We have the inherent capacity to replace these cells. Such spontaneous loss of cells and their renewal is

common in many animals. Time and again, you might have incurred accidental cut or injuries in your body. Such injuries result in the destruction of tissues producing wounds. Your experience will tell you that wounds are healed up and repaired in course of time. In fact, this ability to repair the damaged wound is the characteristic of animals in general. A large variety of animals possess the power to repair and remodel even the lost organ or larger part of the body. Such ability of the fully developed organism to replace lost parts by growth or remodelling of somatic tissue is known as **regeneration**. As mentioned earlier, regeneration is also a developmental process that involves growth, morphogenesis and differentiation in the post-embryonic life. In fact, it is the reawakening of embryonic development in adult life. Therefore, regeneration may be considered as a morphogenetic process, in which replacement or revival of damaged or severed body parts (structures) takes place. As will be revealed later, in some cases, regeneration reaches its climax and leads to the reconstruction of the entire multicellular body from a small fragment of tissue of the individual concerned.

Regeneration Among Animals – a Survey

Some animals exhibit great ability of regeneration. The capacity of regeneration, however, varies widely in different animals. In *Hydra* and *Planaria*, small fragments of the body can give rise to a whole animal; so also in the sponges. When a hydra or a planaria is cut into many pieces, each part reconstitutes itself into a tiny but whole individual

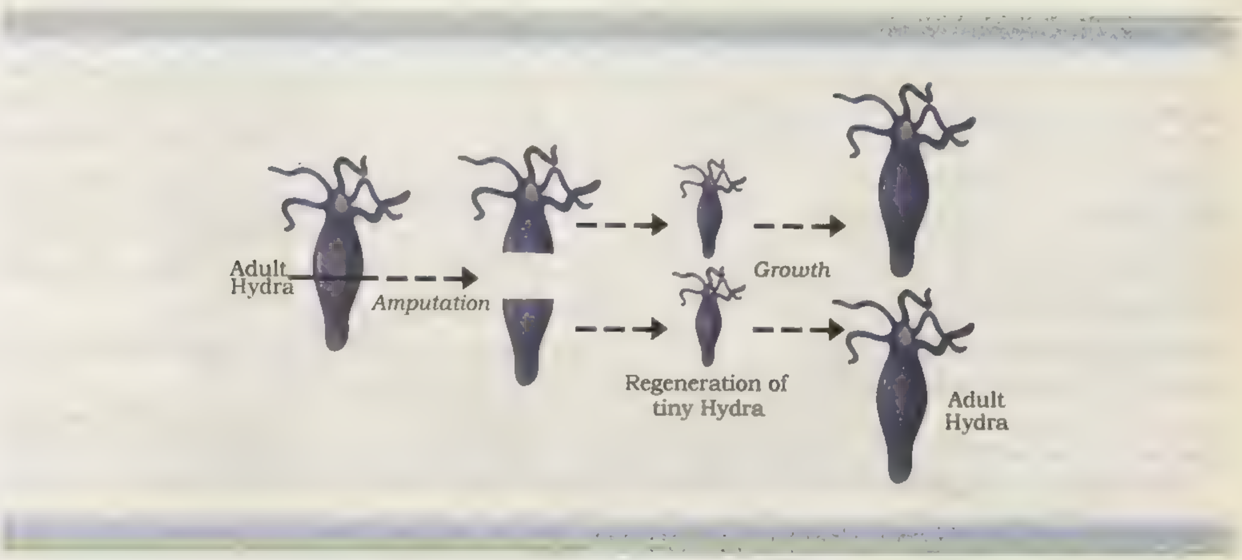


Fig. 15.5 *Regeneration in Hydra*

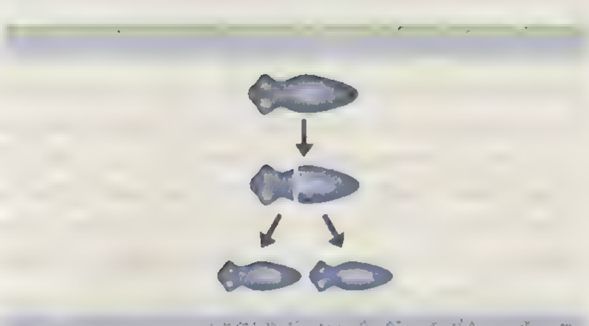


Fig. 15.6 *Regeneration in Planaria*

(Figs. 15.5 and 15.6). The regenerative faculty of hydra is so powerful that it can regenerate perennially its decapitated head. It is virtually immortal and, hence, it has been named so after the mythological monster, **Lerna**, which had seven heads.

Nematodes show very low regenerative ability. Some annelids (e.g., earthworms and their related groups) can renew all of the anterior and posterior body segments after an amputation. But, in majority of annelids this

ability is restricted to the extent of regeneration of four or five segments. Many arthropods (e.g., spiders, crustaceans and insect larvae) can regenerate lost appendages. Regeneration of damaged eyestalks and eyes, and parts of head and foot is observed in some gastropod molluscs. Echinoderms, like starfish, brittle star and sea lily, can regenerate arms and part of the body; sea cucumber can regenerate respiratory organ (tree) and alimentary canal after ejecting them outside the body through the anus. In ascidians, blood cells can give rise to a fully functional organism. Among the amphibians, newts, salamanders and their larvae (tadpole and axolotl) can regenerate a lost tail, limb or external gill. Removal of the lens from the eye of a newt results in the regeneration of a new lens from the pigmented epithelium of the iris. Fish can regenerate their damaged fins. Reptiles, such as lizards, can evade offence by shedding their tails and regenerating it later on. This adaptation is an example of self-mutilation and is called **autotomy**. Birds exhibit no regeneration, except their beak. Although mammals cannot regenerate the lost limb, they can replace to a limited capacity the digits, a part of liver or kidney, if removed. They can also restore fractured bone by a regenerative process. In every case, regeneration is achieved at the tissue level only.

Types of Regeneration

The first stage of regeneration or repair is closure of the wound by the expansion or spread of the adjoining epidermis over the wound. Wound healing is essentially a repair process and found in all animals. Hence, it is thought to be a **repairative regeneration**. Regeneration of the whole animal from a small body fragment in hydra, and limb regeneration in amphibians (e.g., salamanders, newt), are closely linked with developmental processes. However, a clear distinction can be made between the two cases of regeneration. Based on cellular mechanisms, regeneration can be divided into two broad categories : morphallaxis and epimorphosis. In hydra, regeneration occurs mainly by the re-patterning or remodelling of existing tissues and the re-establishment of boundaries. This type of regeneration involves little new growth. Consequently, the regenerated individual initially becomes very tiny; subsequently, it resumes feeding and attains the normal size. Such type of revival is viewed as **morphallaxis** or **morphallactic regeneration**. On the contrary, regeneration of a lost limb (Fig. 15.7) in salamander (amphibian) involves dedifferentiation of adult structures in order to form an undifferentiated mass of cells. These cells are highly proliferating. They accumulate under the epidermis that has already expanded from the margin of the wound and, within next two days, bulge out to form a conical lump. This lump of dedifferentiated cells along with the epidermal covering is called **regeneration blastema** or the **regeneration bud**. These dedifferentiated cells continue to proliferate and eventually redifferentiate to form the rudiment of limb, which eventually transforms into a new correctly patterned limb structure. This type of regeneration is named as **epimorphosis** or **epimorphic regeneration**. In the regeneration of mammalian liver or kidney, the cells divide but do not form an undifferentiated mass of cells or tissues; they produce cells similar to themselves and maintain their differentiated functions. This intermediate type of regeneration is called **compensatory regeneration**.

Factors Controlling Amphibian Limb Regeneration

Amputation of newt's **tail** triggers a complex series of events, which lead to faithful regeneration, both of the mesenchymal tissues of the tail and of the nervous system within it, namely spinal cord and associated ganglia. The mesenchymal progenitor cells of the tail, **blastema cells**, are thought to originate through a process of dedifferentiation similar to that described in the **limb**; and their division is controlled by the nerve and the wound epidermis. Similarly, the proliferation of cells of the regeneration blastema of newt's amputated limb is dependent on nerve fibres. It is thought that the neurons release some **trophic factors**, such as **glial growth factor** (GGF), **fibroblast growth factors** (FGFs) and **insulin-like growth factors** (IGFs). IGFs are necessary for growth and cartilage

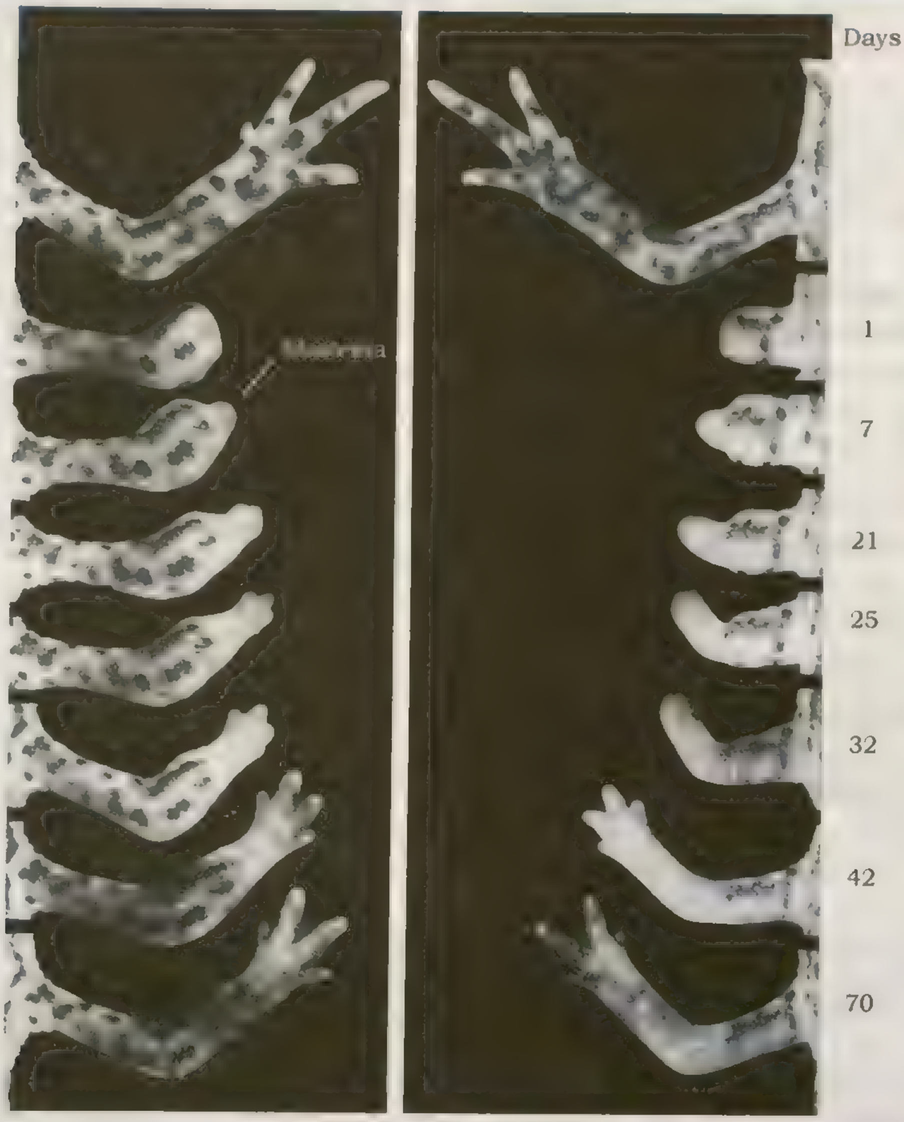


Fig. 15.7 *Regeneration of the forelimb of Newt : (a) Distal amputation, (b) Proximal amputation*

differentiation in tail blastema. Trophic factors expressed by peripheral nerves **support** or **inhibit** limb regeneration in newt and mediate neural effects on blastemal growth. GGF and FGFs are small peptide growth factors with multiple biological functions; they also play significant roles in **patterning**, **growth** and **differentiation**. Another neural agent is **transferrin**, an iron transport protein that is necessary for mitosis in all dividing cells.

15.3 Ageing : The Biology of Senescence

Every organism uses energy from the sun. After developing and maintaining its identity for a definite period of time, it fails to

perform its physiological functions at normal rate. Then, deterioration prevails over synthesis and the organism ages. Entropy, a measure of the disorder or randomness, always wins. **Ageing** can be defined as the time-related deterioration of the physiological functions necessary for survival and fertility. The science of ageing is often referred to as **gerontology**. The scientists studying the science of ageing are known as **gerontologists**.

Maximum Life Span

Ageing affects all the individuals of a species and there are two kinds of life span. One is **maximum life span**, the maximum number of years survived or the greatest age reached by any member of a species. The other is **average life span**, the average number of years survived or age reached by members of a population. **Life expectancy**, the number of years an individual can expect to live, is based on average life spans. It is defined as the age at which half the population still survives. Thus, maximum life span is the characteristic of species and life expectancy is the characteristic of populations.

The maximum life span of wild animals is very difficult to estimate because signs of senility, or extreme old age, are seldom seen in the wild. Animals living under natural conditions rarely approach their maximum possible age because of very high death rates due to infant mortality, diseases, predators, bad weather, accidents, or competition for food and shelter. For this reason, most of the reliable information about the length of the life span comes from zoos, where accurate records are kept and animals live under conditions almost ideally suited to prolong life. The life span of some selected animals is shown in the Table 15.1. The maximum life span of a domestic dog is about 20 years, and that of a laboratory mouse is 4.5 years.

The maximum life span of humans has been estimated to be about 121 years. This rests on the fact that a man in Japan, Shirechiyo Izumi, reached the age of 120 years, 237 days in 1986. He died after developing pneumonia. Average life span and life expectancy of humans have grown dramatically. In general, the rate of mortality of humans has gone down and the life span has increased. It is 56 in India, whereas in the

Table 15.1 : Life Span of Some Animals

Name of Animals	Maximum life span (Years)	Name of Animals	Maximum life span (Years)
Ant Queen	15	Squirrel	16
Carp	47	Guinea-pig	7.5
Toad	36	House Mouse	3.5
Bullfrog	30	House Rat	4.6
Mud Puppy	23	Indian Elephant	70
Giant Salamander	55	Horse	62
Cobra	28	Hippopotamus	49
Turtle	123	Fin Back Whale	80
Alligator	68	Dog	20
Giant Tortoise	152	Cat	28
Humming Bird	8	Lion	30
Parrot	80	Tiger	25
Swan	102	Pig	27
Great Horned Owl	68	Chimpanzee	45
Eagle	55	Rhesus Monkey	29
Turkey Buzzard	118		

United States it is 78. The increase in life span is due to improvements in sanitation, the discovery of antibiotics, and medical care. Genetic, lifestyle and disease processes, all affect the rate of ageing and several distinct processes are involved. Individuals age at extremely different rates. In fact, even within one person, organs and organ systems show different rates of decline. However, some generalities can be made. It is important to remember that these statements do not apply to all people.

Heart : It grows slightly larger with age. Maximal oxygen consumption during exercise declines in men by about 10 per cent with each decade of adult life, and in women, by about 7.5 per cent. However, cardiac output stays nearly the same as the heart pumps more efficiently.

Lungs : Maximum breathing (vital) capacity may decline by about 40 per cent between the ages of 20 and 70.

Brain : With age, the brain loses some cells (neurons) and others become damaged. However, it adapts by increasing the number of connections between cells – synapses – and by regrowing the branch-like extensions, dendrites and axons, that carry messages in the brain.

Kidneys : They gradually become less efficient at extracting wastes from the blood. Bladder capacity declines. Urinary incontinence, which may occur after tissues atrophy, can often be managed through exercise and behavioral techniques.

Body fat : The body does not lose fat with age, but redistributes it from just under the skin to deeper parts of the body. Women are more likely to store it in the lower body – hips and thighs – men in the abdominal area.

Muscles : Without exercise, estimated muscle mass declines 22 per cent for women and 23 per cent for men between the ages of 30 and 70. Exercise can prevent this loss.

Sight : Difficulty focussing close up may begin in the 40s; the ability to distinguish fine details may begin to decline in the 70s. From 50 on, there is increased susceptibility to glare, greater difficulty in seeing at low levels of illumination, and more difficulty in detecting moving targets.

Hearing : It becomes more difficult to hear higher frequencies with age. Hearing declines more quickly in men than in women.

Personality : After about the age 30, personality is stable. Sudden changes in personality sometimes suggest disease processes.

Now, as scientists make headway against chronic diseases like cancer and heart disease, some think that life span of humans can be extended even further. Of late, the dream of extending life span has shifted from legend to laboratory. As gerontologists explore the genes, cells, and organs involved in ageing, they are uncovering more and more of the secrets of longevity.

Causes of Ageing

With ageing, an impairment of physiological functions occurs. This is called **senescence**. Senescence results in the decreased ability to deal with a variety of stresses and an increased susceptibility to diseases. The general senescent phenotype is characteristic of each species. Although there is no consensus on what causes ageing, some cause and effect relationships can be ascertained at the cellular level. Accordingly, the theories of ageing fall into two groups : programmed theories and damage or error theories. The programmed theories stress internal biological clocks or "programmes", whereas the damage or error theories embrace external or environmental forces that damage cells and organs. The **programmed theories** hold that ageing follows a biological timetable, perhaps a continuation of the one that regulates childhood growth and development. The **damage or error theories** underscore environmental assaults to our systems that gradually cause things to go wrong. However, these theories of ageing are not mutually exclusive.

Programmed theories have three sub-categories : Endocrine theory, Programmed Senescence theory and Immunological theory. **Endocrine Theory** holds that biological clocks act through hormones to control the pace of ageing. The idea that hormones are linked to ageing is not new. We have long known that some hormones

decline with age. Human growth hormone (GH) levels decrease in about half of all adults with the passage of time. Production of the sex hormones, estrogen and testosterone tends to fall off. Hormones with less familiar names, like melatonin and thymosin, are also not as abundant in older as in younger adults. The female hormone, **estrogen**, slows the bone thinning that accompanies ageing and may help prevent frailty and disability. After menopause, fat tissue is the major source of a weaker form of estrogen than that produced by the ovaries. The male hormone, **testosterone**, may decline with age, though less frequently or significantly than estrogen in women. Researchers are investigating its ability to strengthen muscles and prevent frailty and disability in older men when administered as testosterone therapy. They are also looking at its side effects, which may include an increased risk of certain cancers, particularly prostate cancer. The hormone, **melatonin**, released from the pineal gland, responds to light and seems to regulate various seasonal changes in the body. As it declines during ageing, it may trigger changes throughout the endocrine system. **Dehydroepiandrosterone** (DHEA), produced in the adrenal glands, is a weak male hormone and a precursor to some other hormones, including testosterone and estrogen. DHEA is being studied for its possible effects on selected aspects of ageing, including immune system decline, and its potential to prevent certain chronic diseases, like cancer and multiple sclerosis. According to **programmed senescence theory**, ageing is the result of the sequential switching on and off of certain genes, with senescence being defined as the time when age-associated deficits are manifested. Studies on immune system reveal that B or T lymphocytes, having the receptors for self-antigens, undergo **programmed cell death** or **apoptosis**. This mechanism eliminates about 90 per cent of all the B cells made in the bone marrow. A parallel process occurs with T cells in the thymus. **Immunological theory** maintains that a programmed decline in immune system functions leads to an increased vulnerability to infectious diseases and thus causes ageing and death.

Damage or **error theories** embrace the aspects of rate of living, free radicals, crosslinking, wear and tear, error catastrophe and somatic mutation as the causes of ageing. **Living theory** opines that ageing is the by-product of metabolism; the greater an organism's rate of oxygen basal metabolism, the shorter its life span. According to **free radicals theory**, accumulated damage caused by oxygen radicals causes cells, and eventually organs to stop functioning. A free radical is a molecule with an unpaired, highly reactive electron. An oxygen-free radical is a by-product of normal metabolism, produced as cells turn food and oxygen into energy. In need of a mate for its lone electron, the free radical takes an electron from another molecule, which, in turn, becomes unstable and combines readily with other molecules. A chain reaction can ensue, resulting in a series of compounds, some of which are harmful. They damage proteins, membranes, and nucleic acids, particularly DNA, including the DNA in mitochondria, the organelles within the cell that produce energy. The damage caused by oxygen radicals is responsible for many of the bodily changes that come with ageing. Free radicals have been implicated not only in ageing, but also in degenerative disorders, including cancer, atherosclerosis, cataracts, and neurodegeneration. **Crosslinking theory** highlights that an accumulation of crosslinked proteins damages cells and tissues, slowing down bodily processes and results in ageing. In a process called **non-enzymatic glycosylation** or **glycation**, glucose molecules attach themselves to proteins, setting in motion a chain of chemical reactions that ends in the proteins binding together or crosslinking, thus altering their biological and structural roles. The process is slow but increases with time. Crosslinks, which have been termed **advanced glycosylation end products** (AGEs), seem to toughen tissues and may cause some of the deterioration associated with ageing. AGEs have been linked to stiffening connective tissue (collagen), hardened arteries, clouded eyes, loss of nerve function, and less efficient kidneys. These are deficiencies that often accompany

ageing. They also appear at younger ages in people with diabetes, who have high glucose levels. Diabetes, in fact, is sometimes considered an accelerated model of ageing. Not only do its complications mimic the physiologic changes that can accompany old age, but also its victims have shorter-than-average life expectancies. As a result, much research on crosslinking has focussed on its relationship to diabetes, as well as ageing. **Wear and tear theory** holds that cells and tissues have vital parts that wear out to bring up ageing. In the normal wear and tear of cellular life, DNA undergoes continual damage. Attacked by oxygen radicals, ultraviolet light, and other toxic agents, it suffers damage in the form of deletions, or destroyed sections and mutations, or changes in the sequence of DNA bases that make up the genetic code. DNA is damaged throughout life; the repair process may be a major factor in ageing, health and longevity. Biologists theorise that DNA damage leads to malfunctioning of genes, proteins, cells and deterioration of tissues and organs. It is known that an animal's ability to repair certain types of DNA damage is directly related to the life span of its species. Humans repair DNA, for example, more quickly and efficiently than mice or other animals with shorter life spans. This suggests that DNA damage and repair are in some way, part of the ageing puzzle. The **theory of error catastrophe** asserts that damage to mechanisms that synthesise proteins, results in faulty proteins, which accumulate to a level that causes catastrophic damage to cells, tissues, and organs. **Somatic mutation theory** advocates that genetic mutations occur and accumulate with increasing age, causing cells to deteriorate and malfunction.

Ageing and Death

Biological ageing affects everybody. Ageing is a deleterious process, involving the functioning of cells, and therefore, organs, and finally, the organism itself. This process is subtle in most cases, usually manifesting itself when the changes become extreme, or not until the system as a whole is stressed. As we age, the amount of stress required to cause a breakdown in the health of the organism falls. Likewise, death is also a biological event that occurs due to breakdown in body functioning. This is caused, usually due to shortfall of oxygen supply to the tissues. Causes of human death are many. Firstly, tissues of vital organs (like heart, liver, lung, kidney, etc.) become weakened due to ageing. These affect the proper functioning of physiological processes, including metabolic disorders. Death becomes inevitable in course of time. Secondly, malfunction of body's immune system reduces the resistance of the body to different antigens. As a result, the individual becomes vulnerable to many diseases.

Although death is often related with age, it is not known if the process of ageing itself is a disease or a natural process of the organism. There is no answer as yet, whether there is a built-in general death factor, or whether humans will be immortal if all diseases are conquered. Scientists are trying to distinguish between changes which are associated with normal ageing, and those associated with external or internal pathological effects. Osteoporosis is a good example of this problem. This disorder predisposes an individual to bone fractures. It is generally regarded as an age-related disease, particularly severe in post-menopausal women. However, there are also a number of pathological conditions that predispose one to this disorder, or are associated with the development of osteoporosis, such as prolonged immobility, poor nutrition, and excessive alcohol intake or corticosteroid treatment. Another prominent example is impairment in body temperature control. It is partly assumed to be due to the ageing process, but it may be made worse by cerebrovascular disease or the dementing process, such as Alzheimer's disease. Postural hypotension is another of those problems that have both age-related and pathological sources. What appears to happen in most of the age-related vulnerabilities is that physiological systems decline with age, resulting in a shift in the accuracy of the body to control the chemical and cellular environment, and thus, leaving individuals more prone to diseases of ageing.

SUMMARY

Growth is the central aspect of all developing systems. Growth in animals occurs after the basic body plan has been laid down. Growth involves cell proliferation, cell enlargement and secretion of large amounts of extracellular matrix. Based on the relation of cell division with the growth of the organisms, three basic types of cellular growth – auxetic, multiplicative and accretionary – can be identified. All higher animals grow at a specific rate and rhythm. Animals grow at different rates at different period of life. Plotting weight of an animal, taken at regular interval, against time on one can draw growth curve. This curve is S-shaped and is known as sigmoid curve. It represents the increase of the mass of the animal.

In mammals, insulin-like growth factors (IGFs) are required for normal embryonic growth. These factors mediate the effects of growth hormone after birth. Human embryonic and post-embryonic growth is largely controlled by growth hormone, which is made in the pituitary gland. Growth rate of a growing tissue depends on the rates of both cell proliferation and cell death.

Regeneration is the ability of the fully developed organism to replace a lost part of its body. It is a revival of morphogenesis in the post-embryonic life. Many animals exhibit great ability to regenerate. In mammals, regeneration is achieved at the tissue level only. The two main mechanisms involved in regeneration are morphallaxis, and epimorphosis. In hydra, regeneration occurs mainly by morphallaxis in which the remodelling of existing tissues and the re-establishment of boundaries take place. Regeneration of limb in amphibians involves epimorphosis : a blastema is formed by dedifferentiation of cells, which divide, and eventually redifferentiate to form the new correctly patterned limb structures. Regeneration of mammalian liver or kidney is attained by compensatory regeneration : the cells divide but do not form an undifferentiated mass of cells or tissues; they produce cells similar to themselves and maintain their differentiated functions. Regeneration of limb and tails in newts is controlled by some trophic factors.

Ageing can be defined as the time-related deterioration of the physiological functions necessary for survival and fertility. Ageing is largely caused by wear and tear. The maximum number of years survived, or the greatest age reached by any member of a species is called maximum life span. Average life span denotes the average number of years survived or age reached by members of a population. The number of years an individual can expect to live is known as life expectancy. The maximum life span is the characteristic of species, but life expectancy is the characteristic of populations. Ageing leads to an impairment of physiological functions, called senescence. Programmed theories of ageing hold that ageing follows a biological timetable, perhaps a continuation of the one that regulates childhood

growth and development. The damage or error theories underscore environmental assaults to our systems that gradually cause things to go wrong. However, these theories of ageing are not mutually exclusive. Although ageing is largely caused by wear and tear, it is also under genetic control.

Ageing is a deleterious process. With age, the amount of stress required to cause a breakdown in the health of the organism falls. Death is also a biological event that occurs due to breakdown in body functioning. It is not known if the process of ageing itself is a disease or a natural process of the organism. However, physiological systems decline with age, resulting in a shift in the accuracy of the body to control the chemical and cellular environment, and thus, leaving individuals more prone to diseases of ageing.

EXERCISES

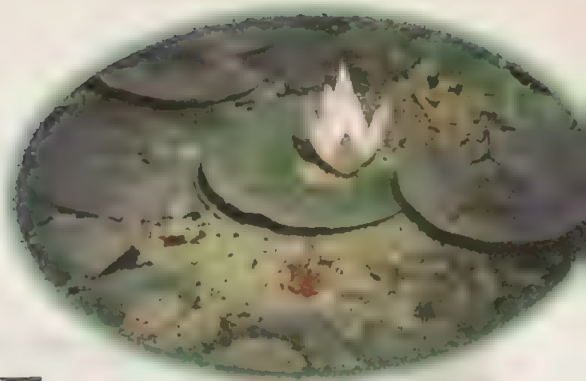
1. Define growth. What is degrowth?
2. What are the basic types of cellular growth?
3. What is a sigmoid curve? Why is it so called?
4. Name three hormones/factors that help in growth.
5. Differentiate between auxetic growth and multiplicative growth.
6. What is accretionary growth?
7. What is regeneration? Give some examples.
8. What is morphallaxis? How does it differ from epimorphosis?
9. __________ and ___________ exhibit great ability of regeneration.
10. ________________ is an iron transport protein necessary for mitosis in all dividing cells.
11. ________________ may be considered as reawakening of embryonic development in adult life.
12. Nematodes show very ________________ regenerative ability.
13. What is ageing ?
14. What is autotomy?
15. Mention the factors controlling amphibian limb regeneration.
16. Distinguish between compensatory regeneration and epimorphic regeneration.
17. Distinguish between repairative regeneration and morphallactic regeneration.
18. What is gerontology?
19. What is senescence?
20. Write in brief the programmed senescence theory.
21. What is apoptosis?
22. Write down the aspects of damage or error theories of senescence.

23. What is Alzheimer's disease?

24. How do free radicals make senescence faster?

25. Match the items of Column I with that of Column II :

Column I	Column II
(i) accretionary growth	(a) science of ageing
(ii) gerontology	(b) self-mutilation
(iii) somatic mutation theory	(c) erythropoiesis
(iv) autotomy	(d) cells malfunction
	(e) Programmed cell death



UNIT NINE

ECOLOGY AND ENVIRONMENT

Chapter 16

- Organisms and The Environment

Chapter 17

- Population, Biotic Community and Succession

Chapter 18

- Ecosystem : Structure and Function

Chapter 19

- Natural Resources [illegible]

Chapter 20

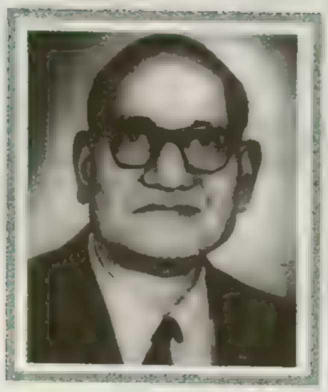
- [illegible]

Chapter 21

- [illegible]

The growth and reproduction of all living organisms are affected by the environment in which they live. On the other hand, by their activities the living organisms themselves affect their environment. Climate and soil are important components of environment. Plants and animals are commonly adapted to variations in environmental factors in different habitats. The reciprocal relationships between organisms and their environment are primarily studied at the levels of population, community and ecosystem, which represent a hierarchy of organisation with increasing complexity. The ecosystems are functionally independent units of nature, showing characteristic energy flow and nutrient cycling. The wide variety of ecosystems occurring in the world can be grouped into biomes having specific characteristics (e.g., forest, grassland and desert). Ecosystems provide a variety of services to mankind. They also provide many resources for use as food, fodder, shelter, etc. However, the increasing human activities, especially during the last millennium, have adversely affected biodiversity at all levels (genetic, species and ecosystem). Therefore, conservation of biodiversity has assumed greater significance in the present time. Human activities like industrialisation, power generation, urbanisation, etc., are strongly polluting our life-support system (air, water and soil). Such activities are also leading to an increase in greenhouse gases in the atmosphere causing the recently recognised phenomena of global warming and ozone hole.

In this unit, we will learn about : the interactions between the organisms and environment, and the adaptations of organisms; the characteristics and growth of populations, the interactions and succession in biotic communities; the structure and functioning of ecosystems, and ecological features of major terrestrial biomes; the natural resources and their conservation; the biodiversity at various levels, causes of its loss, and conservation measures; and causes and consequences of environmental pollution and global change.



RAMDEO MISRA

(1908-1998)

Prof. Ramdeo Misra is revered as the Father of Ecology in India. After obtaining Ph.D in Ecology (1937) under Prof. W. H. Pearsall, FRS from Leeds University in UK, he returned to establish ecology teaching and research at the Department of Botany of the Banaras Hindu University. Under his leadership, this Department gained international recognition for research in ecology of tropical ecosystems (forests, grasslands, ponds, lakes, etc.). His researches laid the foundations for understanding of tropical communities and their succession, environmental responses of plant populations, and productivity and nutrient cycling in tropical forest and grassland ecosystems. Prof. Misra formulated the first postgraduate course in ecology in India. Over 50 scholars obtained Ph. D degree under his supervision and moved to other Universities and research institutes to initiate ecology teaching/research across the country. He was honoured with the Fellowships of Indian National Science Academy and World Academy of Arts and Science, and the prestigious Sanjay Gandhi Award in Environment and Ecology. Due to his efforts, the Government of India established the National Committee for Environmental Planning and Coordination (1972) which, in later years, paved the way for the establishment of the Ministry of Environment and Forests (1984). The International Society for Tropical Ecology (headquarters at BHU) founded by Prof. Misra in 1956 has played a significant role in addressing ecological issues in tropics.

Chapter 16

Organisms and the Environment

In nature, organisms can survive only in appropriate environments, interact with each other, and are influenced by the whole complex of environmental factors. **Ecology** is the branch of biology that deals with the study of interactions between organisms and their environment. An understanding of ecological principles is needed for the sustainable use of resources, and to evolve strategies for the mitigation of environmental problems at local, regional and global levels. In this chapter, you will learn the effects of environmental factors on organisms, the significance of the range of tolerance, and adaptations of organisms to varying physical environmental conditions.

16.1 Levels of Organisation

In ecology, we study the distribution and abundance of organisms, their interactions among themselves and with the physical environment. The latter is comprised of lithosphere, hydrosphere and the atmosphere (Fig.16.1). The word ecology, as given by a German biologist, Ernst Haeckel, in 1869, has its origin from the Greek word, *Oikos* meaning 'home', and *logos* meaning 'to study'. Like other fields of learning, the developments in the field of ecology have been gradual. Ecology has progressed from natural history and biogeography to ecosystem ecology. More recently, global ecology with an emphasis on climate change, biodiversity conservation and ecological sustainability has been emphasised.

Biology is a field of enquiry from genes to the ecosystems, forming a spectrum of several levels of organisation. These levels, in the ascending order of complexity, include the genes, cells, tissues organs, individual organism, population, biological community, ecosystem, landscape, biome and the biosphere. In ecology we study about the organisms, populations, biological community, ecosystem, landscape and the biosphere. It should be understood

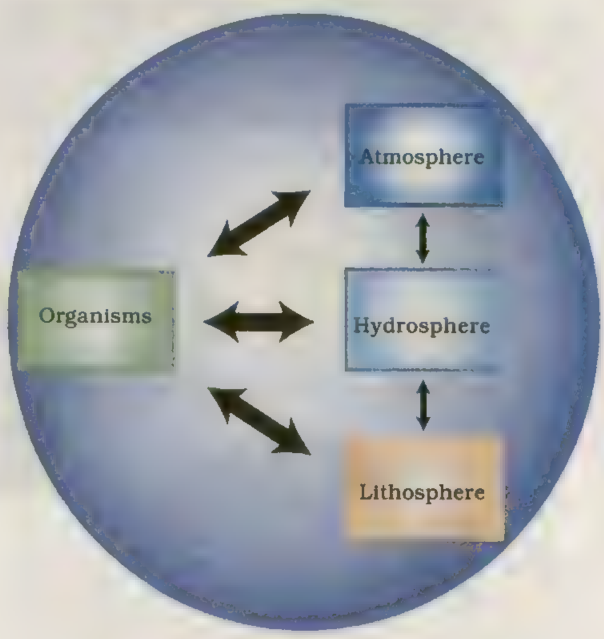


Fig. 16.1 *The organisms interact with physical environment comprised of atmosphere, hydrosphere and lithosphere*

that one level of organisation integrates with the other levels, and there are no sharp lines or breaks in the functional sense among various levels. For example, an organism

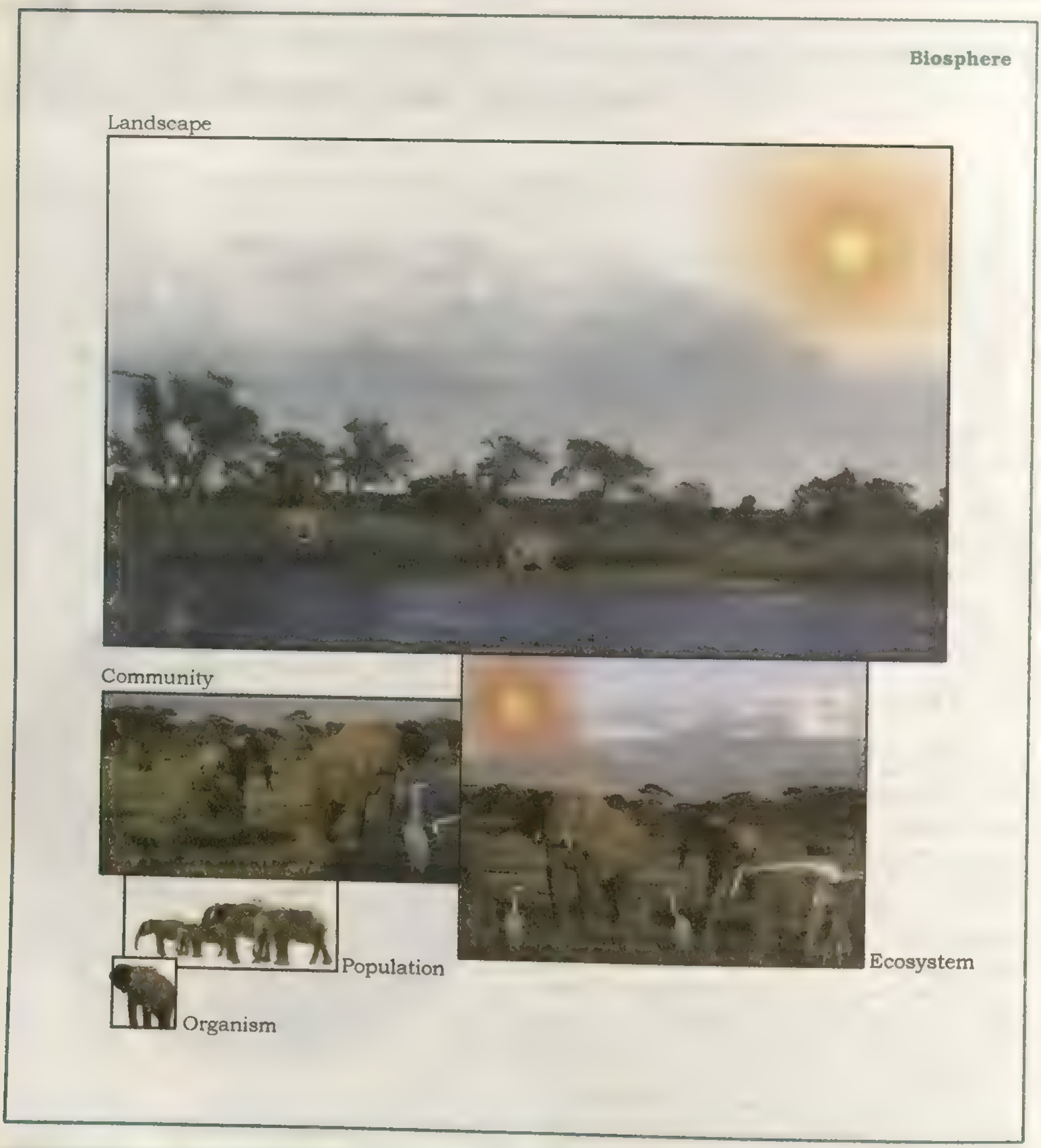


Fig. 16.2 *In ecology, levels of biological organisation range from organism to biosphere*

occurring with other individuals of the same species, forms a part of a population. Similarly, a biological community is sustained only due to the cycling of nutrients and flow of energy in the ecosystem.

The ecological levels of organisation are briefly described below.

Organisms are the basic unit of study in ecology. At the level of organism, we intend to understand the form, physiology and behaviour, distribution and adaptations in relation to the environmental conditions. Similar organisms having the potential for interbreeding and producing fertile offspring constitute what we call **species**. **Population** is a group of individuals of a plant or an animal species, inhabiting a given area. For example, all individuals of elephants in an area constitute its population. We also study how two populations interact, a predator with its prey, or a parasite with its host. Competition, mutualism and predation are various types of interactions between organisms. The **biological community** is an assemblage of populations of plants, animals, bacteria and fungi that live in an area and interact with each other. A biological community has a distinct species composition and structure. An **ecosystem** is composed of a biological community, integrated with its physical environment through the exchange of energy and recycling of the nutrients (Fig.16.2). The structure and functioning of ecosystem shall be described in detail in Chapter 18.

A **landscape** is a unit of land with a natural boundary having a mosaic of patches. These patches generally represent different ecosystems. A **biome** is a large regional unit characterised by a major vegetation type and associated fauna found in a specific climatic zone. Some examples of terrestrial biomes are desert, temperate deciduous forest, tropical rain forest, etc. On a global scale, all the earth's terrestrial biomes and aquatic systems constitute the biosphere. The biosphere consists of the lower atmosphere, the land and the oceans, rivers and lakes, where living organisms are found.

16.2 Environment, Habitat and Niche

Environment

Environment is the sum total of all biotic (living) and abiotic (non-living) factors that surround and potentially influence an organism. Some components of the environment serve as resource, while others act as a regulatory factor. The different components of the environment are interlinked and interdependent.The environment can be understood both at large and small scales. This is reflected in regional and global climatic patterns, as well as the local climatic conditions, the microclimate.

Spatial and Time Scales of Environment

Most organisms interact with their environment at several spatial and time scales. A single bacterium in soil, for example, interacts with air and water within a fraction of a cubic centimeter space. On the other hand, a tree interacts with a large volume of air, water and soil at a large spatial scale. The environment varies from place to place due to variations in climate, soil type and topography. The activities of organisms influence the hydrosphere, the lower atmosphere and the near-surface part of the lithosphere, through exchanges of matter and energy. Organisms have to cope with the external environment over a range of time scales, varying from few minutes to days, seasons or over a much longer period of geological time scale. For example, phytoplankton populations may change within a few days with the change in light conditions in aquatic systems. On the other hand, the variations in lithosphere occur very slowly over a long period of time.

Climate

The short-term properties of the atmosphere (such as temperature, pressure, humidity, rainfall, sun shine, cloud cover and wind), at a given place and time, are what we call **weather**. Climate is the average weather of an area, including general patterns of atmospheric conditions, seasonal variations and weather extremes averaged over a long period. Thus, while weather reflects the hourly, daily or weekly changes in the above properties, climate entails longer periods, such as seasons,

or years. Temperature and rainfall are the two most important factors which determine the climate of an area. Global variations of temperature and rainfall result from differential input of solar radiation in different regions, and from the redistribution of heat energy by winds and ocean currents. Variations in temperature, rainfall, and humidity in different regions of the globe form global climate patterns, which govern all life on earth.

Climatic zones : On the basis of variation in mean temperature along latitude, the main climatic regions are :

(i) Tropical (0°-20° latitude)
(ii) Subtropical (20°-40° latitude)
(iii) Temperate (40°-60° latitude)
(iv) Arctic and Antarctic (60°-80° latitude).

The mean temperature declines as we move from tropical to arctic region. A similar climatic zonation occurs with increasing altitude in the mountains. A mountain located in a tropical region will successively have tropical, subtropical, temperate and alpine zones with increasing altitude. Similarly, in temperate zone, the high altitudes will have alpine climatic conditions. Within each temperature-based climatic zone, the annual precipitation (rainfall and/or snowfall) varies considerably. These two factors, temperature and precipitation, together determine the vegetation and soil types.

Microclimate

The microclimate represents the climatic conditions that prevail at a local scale, or in areas of limited size, such as the immediate surroundings of plants and animals. Microclimate generally differs from the prevailing regional climatic conditions. For example, in a forest, dense foliage reduces the amount of light reaching the ground. This also results in a changed air temperature profile. The day-time air temperature inside the forest is lower than outside. Also, the interior of a forest may be more humid than a nearby non-forested area.

Habitat and Niche

The place where an organism lives is called its habitat. **Habitats** are characterised by conspicuous physical features, which may include the dominant forms of plant and animal life. We may also understand that habitat may refer to the place occupied by an entire biological community. For example, a large number of species are found in a forest habitat. Plants and animals, as influenced by the environmental conditions of a particular habitat, indicate some specific traits. For example, plants growing on saline soils have several characteristics that are not found in other plants.

A habitat can contain many ecological niches and support a variety of species. The **ecological niche** of an organism represents the range of conditions that it can tolerate, the resources it utilises, and its functional role in the ecological system. Each species has a distinct niche, and no two species are believed to occupy exactly the same niche.

16.3 Environmental Factors

We know that the physical environment consists of factors like air, light, heat, water, soil and wind. These abiotic factors determine the success of an organism through their effect on structure, life-history, physiology and behaviour. Growth and reproduction of an organism are also affected by biotic factors, which include all other organisms in the habitat.

A brief account and role of various factors in physical and biological processes is given below.

Atmosphere

Atmospheric layers : The atmosphere is divided into a series of concentric shells or spheres, due to variations in temperature and pressure at various altitudes. These spheres are : troposphere, stratosphere, mesosphere and thermosphere (Fig. 16.3).

Troposphere : The lower portion of the atmosphere, extending to about 8-16 km height from the earth surface, is known as troposphere. It contains more than 90 per cent of gases in the atmosphere. Generally, temperature decreases with increasing height up to **tropopause** (top of troposphere).

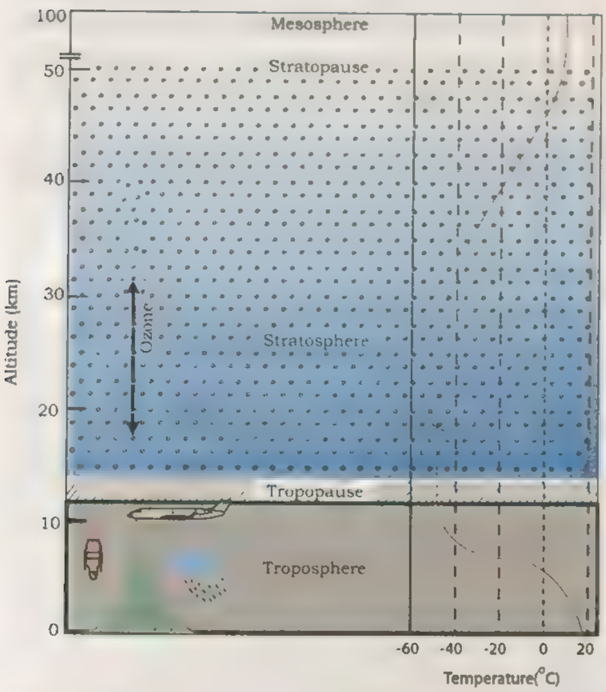


Fig. 16.3 *The vertical layering of the atmosphere from the earth's surface to about 120 km altitude. Note the temperature difference in different layers*

The temperature averages 15°C near the soil surface, and it lowers down to –57°C at the tropopause, which marks the transition to the stratosphere.

Stratosphere : It extends up to 30-50 km. There is little mixing of gases between the troposphere and stratosphere. A thin layer of ozone is present in the stratosphere at the height of 15 to 30 km. **Stratopause** is the transition layer between stratosphere and the mesosphere.

Mesosphere : Beyond stratosphere, it extends up to an altitude of 80 km and shows a decrease of temperature with height.

Air composition : Nitrogen and oxygen are the most abundant gases in the troposphere, constituting 78 per cent and 20.9 per cent of the total gaseous volume, respectively. The remaining 1 per cent is Argon, water vapour, carbon dioxide, ozone and other gases. Water vapour, CO_2 and ozone occur in minute quantities in the atmosphere, but are essential for maintaining life on the earth. Water vapour regulates the hydrological cycle sustaining life in both terrestrial and an aquatic ecosystem, as well as it absorbs infrared radiation from the earth. Carbon dioxide, water vapour and ozone play an important role in maintaining the heat balance of the earth. The composition of the atmosphere is a product of the activities of living organisms.

Gases in water : In the aquatic systems, oxygen, carbon dioxide, and other gases are partially dissolved in water. Oxygen may be a limiting factor for the growth of phytoplankton and other aquatic organisms, generally in deep lakes, or in waters receiving heavy load of organic materials. The oxygen supply in water is regulated through diffusion from the air and from photosynthetic activity of aquatic plants. Carbon dioxide is highly soluble in water and may be present in variable amounts. It combines with water to form carbonic acid (H_2CO_3), which, in turn, reacts with available limestone to form carbonates (CO_3^{2-}) and bicarbonates (HCO_3^-).

Light

Electromagnetic spectrum : You know that sun is the ultimate source of energy for most of the organisms on earth, directly or indirectly. Solar radiation, before entering the atmosphere (at 83 km above the earth surface), carries energy at a constant rate of 2 cal cm^{-2} min^{-1}, which is known as the **solar constant**. Solar spectrum comprises short wave radiation, light, and long wave radiation. The short wave radiations include cosmic rays, X-rays and ultraviolet rays, which have wavelengths shorter than 0.4 μm or 400 nm. Light or visible spectrum having wavelengths of 400 – 700 nm is also called **photosynthetically active radiation** (PAR).

The infrared wavelengths are longer than 740 nm (Fig. 16.4). The ultraviolet radiation (wavelengths 100 nm – 400 nm) is mostly absorbed by ozone layer present in the stratosphere, and only a small fraction of it reaches the earth's surface. Depending upon the wavelength, three types of ultraviolet radiation are distinguished : **UV-C** (100 nm – 280 nm), **UV-B** (280 nm – 320 nm) and **UV-A** (320 nm – 400 nm). Out of these three, UV-C radiation is lethal.

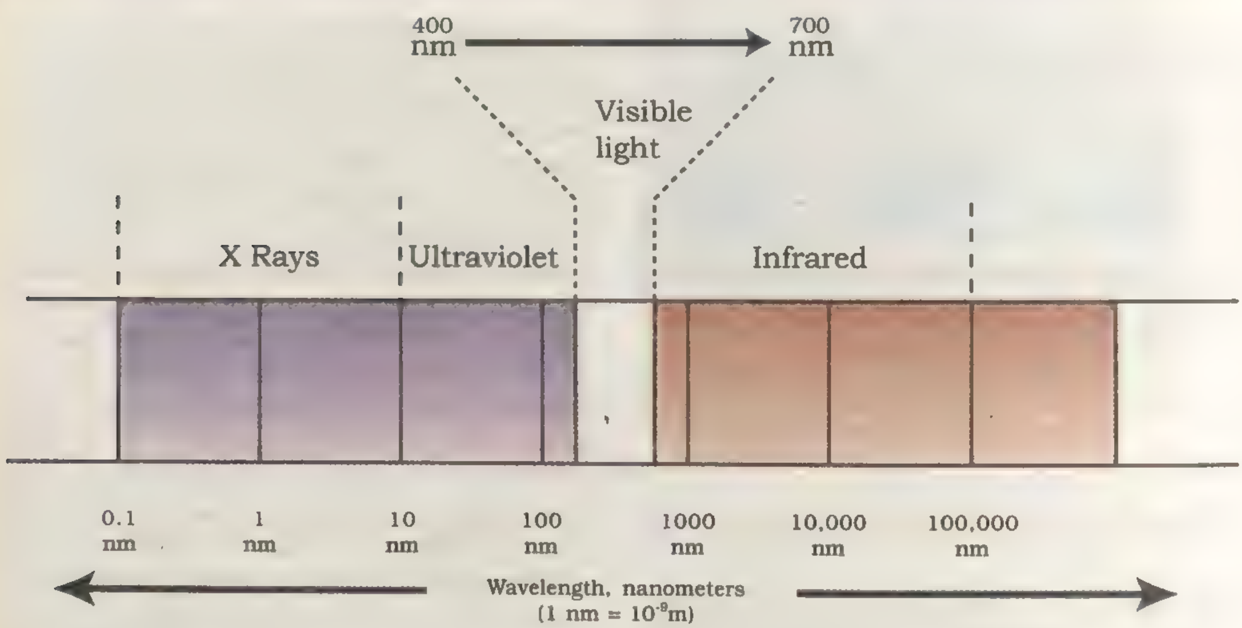


Fig. 16.4 *The electromagnetic spectrum of solar radiation*

Effects of light on plants **:** The quality (wavelength), the intensity (energy measured in joules) and duration (length of day) of light are important to organisms. The intensity of light varies with latitude and time of the day. Light, you have studied earlier, affects the processes of photosynthesis, growth and reproduction in plants. The quality of light plays an important role in flower induction, seed germination and plant movements. The duration of light regulates the phenological processes, such as flowering and fruiting, in plants. **Phenology** refers to the timing of seasonal activities of plants in relation to change in environmental conditions. In many animals, migration, hibernation and reproductive behaviours are controlled by the relative lengths of day and night.

Effects on aquatic systems **:** Life activity under water is often controlled by the availability of light. Light is frequently a limiting factor for plants in deep waters, such as in oceans and deep lakes. In aquatic systems, the presence of light determines where producers

and consumers are to live in water. For example, the phytoplanktons (*phyto* : plant; *plankton* : small) live in the illuminated surface layer of water, whereas benthic organisms live in, or at, the sediments of a lake. There are three zones in a lake, depending upon penetration of light : (i) The **littoral zone** is the shallow water zone around the edge of the lake which supports rooted vegetation; light penetrates through the shallow water (Fig. 16.5). (ii) The open water zone beyond the littoral zone is the **limnetic zone**, where phytoplankton grow in abundance. In the limnetic zone, light may penetrate up to 20 to 40 m, depending upon the clarity of water. (iii) The dark zone, where light does not reach, is known as the **profundal zone**. The sediments at the bottom of lakes and ponds form the **benthic** region which is a habitat for benthic organisms like snails, slugs and micro-organisms.

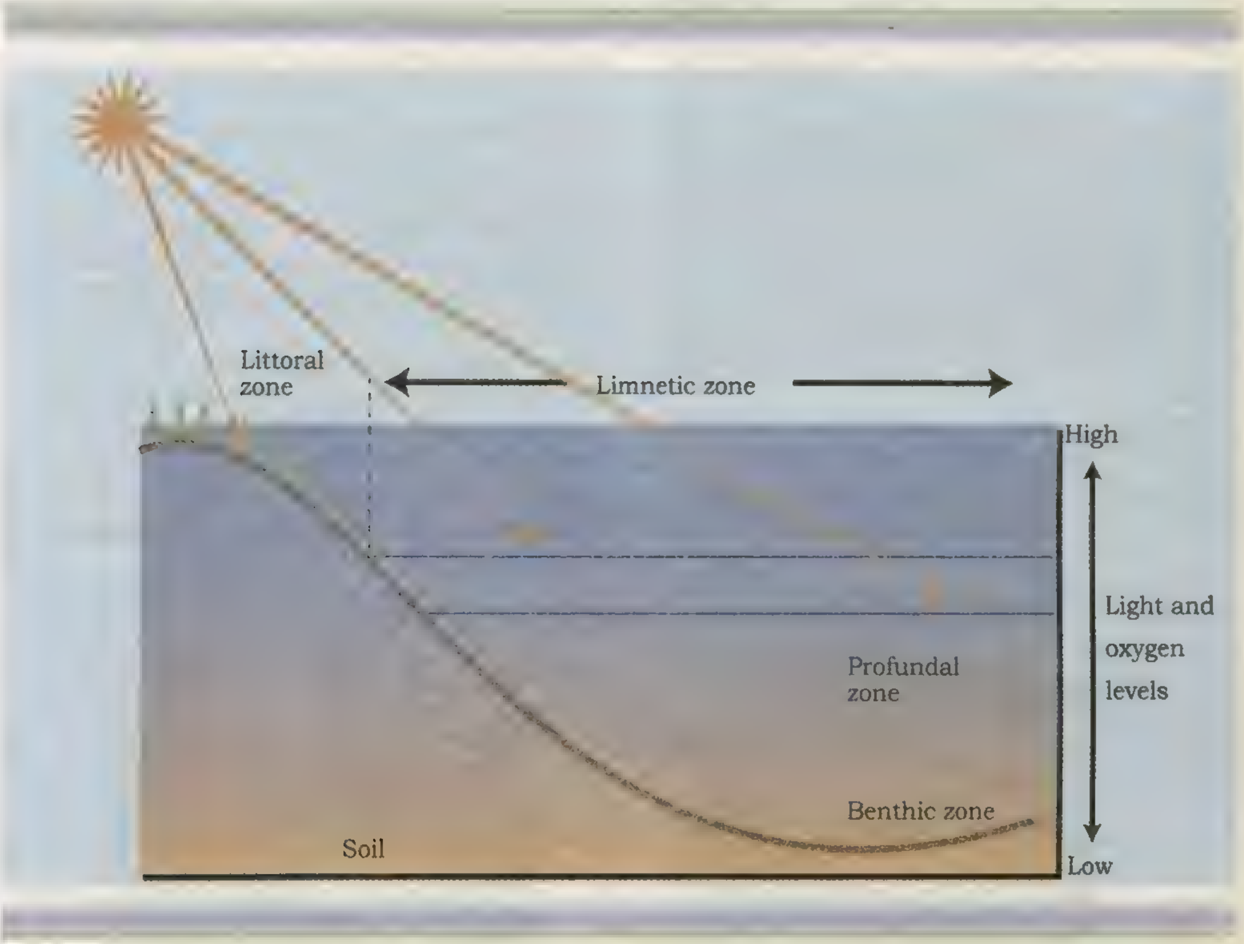


Fig. 16.5 *The zones in lake water as determined by gradients of light, oxygen and temperature from the water surface to lake bottom*

Temperature

Temperature is the degree of hotness or coldness of a substance. The factors which influence variation in temperature include latitude, altitude, topography, vegetation and slope aspect. The vertical temperature gradient over earth's surface is called **lapse rate**, the value being 6.5°C per 1000 m elevation. Temperature has a significant effect on the climatic conditions, growth responses of plants,

and activities of organisms. Temperature may act as a stimulus for plants, determining the timing of their development. For example, thermoperiodism (a day-night temperature differential) is essential for optimum growth of some plants. Exposure to cold enhances seed germination, as well as induces flowering in some plants.

Thermoregulation and homeostasis : Temperature is important in controlling the rate of processes inside an organism and also its activities. In **ectotherms** (cold-blooded animals), the body temperature tends to match with the environmental temperature in which they live. Many active ectotherms, such as frogs and snakes, control their body temperature by moving around or by seeking shade. Some ectotherms are nocturnal and they feed during the night.

Endotherms (warm-blooded animals) regulate their body temperature by physiological means and maintain a more or less constant internal temperature, even when the temperature outside fluctuates (birds and mammals). They have physiological mechanisms for keeping body temperature constant or within tolerance limits. You may recall that the maintenance of relatively constant internal environment under varying external environment is called **homeostasis**. Maintaining a constant body temperature in the case of endotherm animals provides them a metabolic advantage over other organisms. We know that biochemical pathways and enzymes often function at their maximum at a temperature near 37°C in endotherms. Therefore, these animals are able to remain active even under cold conditions by exhibiting different types of adaptations to minimise the loss of heat.

Thermal stratification in lakes : Differences in temperature of water at different depths result in thermal stratification in deep water bodies. During summer, temperature is higher in the surface water, which is separated from the deeper water mass by a **thermocline**

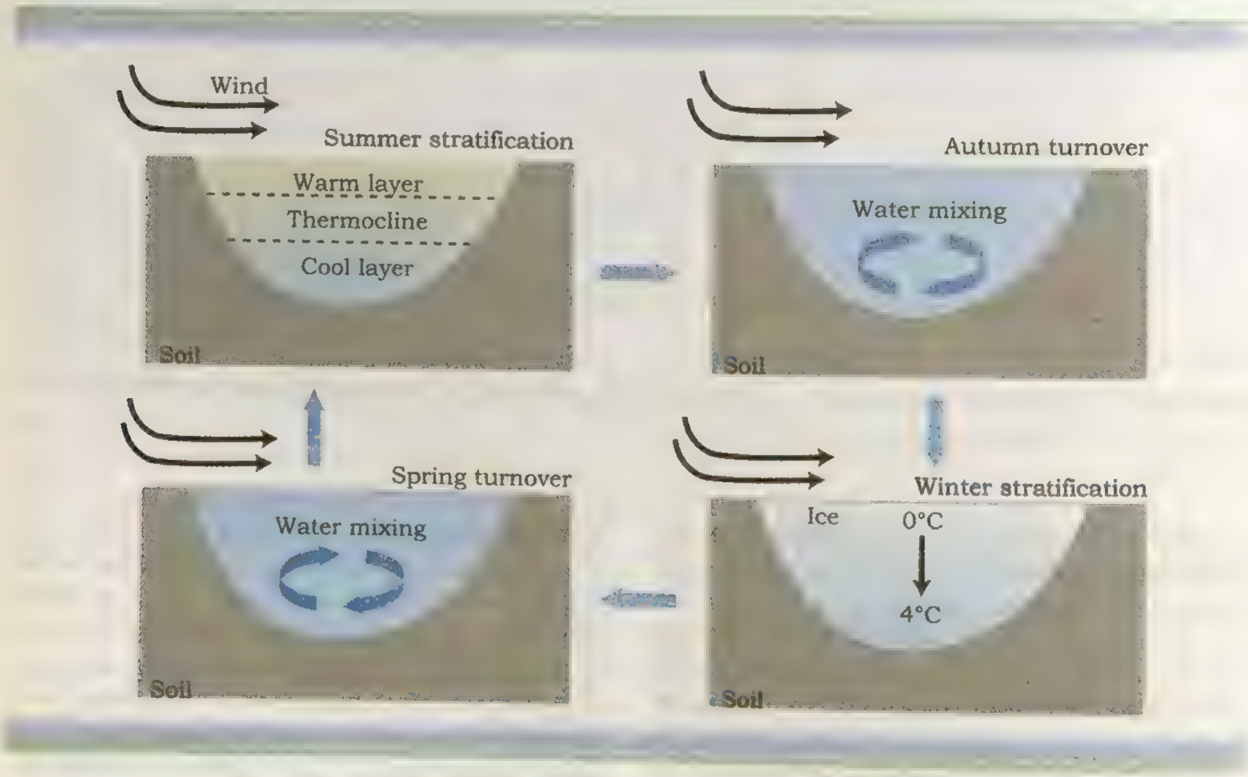


Fig. 16.6 *Thermal stratification occurs in lakes. The seasonal mixing patterns of a temperate lake are determined by its temperature profile*

(a zone of gradual change in temperature). A thermocline often creates two different layers, i.e., **epilimnion** (upper layer of water) and the **hypolimnion** (lower layer of water) in a single body of water (Fig. 16.6). During winter, in a temperate lake, water is at freezing temperature on the surface, whereas in the lower layer temperature is about 4°C. The surface water is cooled during autumn, and warmed in spring. This results in a free mixing of water in the whole water body, also known as autumn and spring turnover (Fig. 16.6). This turnover redistributes oxygen and nutrients, resulting in a bloom of phytoplankton growth. During the stratified conditions, both in winter and summer, growth of phytoplankton is low due to low nutrients and oxygen availability.

Water

Water, the only inorganic liquid occurring naturally on earth, can function as a resource, condition or a habitat. The total amount of water on earth remains the same; however, it moves from one place to another and regulates various processes in organisms. Water regulates the climate through its role in rainfall distribution and temperature modification. It has significant effect on vegetation type and its composition.

Hydrological cycle : The hydrological cycle is the movement of water between aquatic systems, air and land. Water vapour, an important constituent of the atmosphere, can condense to form clouds, and eventually rainfall. Plants play an important role in the hydrological cycle through the process of transpiration. In tropical forests, as much as 75 per cent of annual rainfall is returned to the atmosphere by plants, which recharges the atmospheric water vapour. When atmosphere contains enough moisture, it condenses to form fog, cloud, rain or snow. Rainfall is uneven on the surface of earth. Deserts receive very low rainfall, (<100 mm $year^{-1}$) each year. On the other hand, some areas receive high rainfall (for example, Cherrapunji and Mawsynrain (Meghalya) receives >11,000 mm rainfall every year).

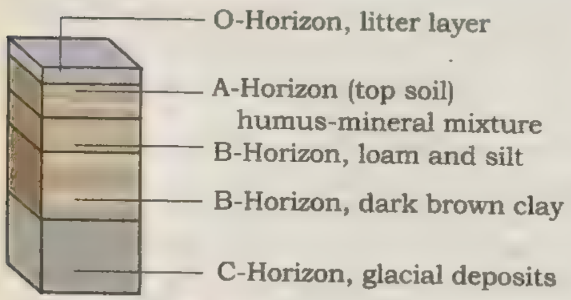
Plant-water relations : For land plants, the main source of water is rainfall or melting of snow. Water potential is the force with which soils hold water and it is quantified in terms of pressure. At sea level, pressure exerted by the atmosphere is one bar which equals about 0.1 megapascals (MPa). The upper limit of water availability of a soil is called **field capacity**. The water potential of a soil at field capacity is around – 0.01 MPa. The lower limit of water availability in soil is known as **wilting point**, having a water potential of –1.5 MPa. With increase in the negative values of water potential, the water availability to plants is reduced. It is the osmotic potential in the roots of plants which causes water to enter the roots from the soil. Plants have adapted to variations in water availability by habitat selection, phenological adjustments, or by having higher water use efficiency.

Soil

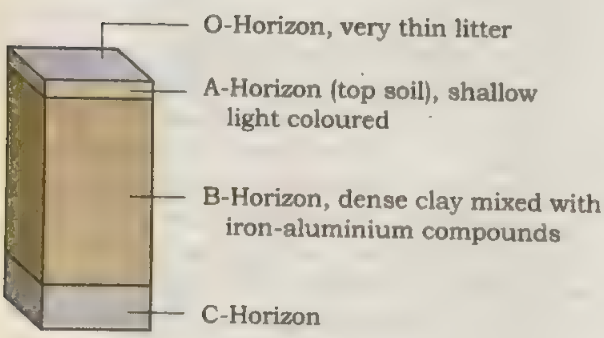
Soil is the uppermost weathered layer of earth's crust and is composed of minerals and partly decomposed organic matter. It is formed due to interactions among parent rock, climate, living organisms, time and topography. Soil plays an important role in plant growth by providing water, nutrients and anchorage. Soils support the growth of crops, grassland and forests, on which we depend for food, fibre, wood and building materials. The mineral composition of soils depends on the minerals in the parent material and the extent of weathering.

Soil profile : The vertical layered structure of soil is called the soil profile. Soil profile develops due to weathering process, accumulation of organic matter and the leaching of mineral matter. The soil profiles of a temperate deciduous forest and a tropical rain forest are compared in Figure 16.7. There are four main horizons in a soil profile : the O-horizon is the organic layer composed of recognisable dead organic residues; the A-horizon, also called the top soil, is the uppermost mineral layer, which also contains roots and partially decomposed organic matter; the B-horizon is the subsoil, and the C-horizon represents the less weathered parent material. The soil profile development is mainly governed by the climate and the kind of vegetation.

Soils in grassland, forest and desert biomes differ markedly in colour, clay, organic matter content, and depth. In desert soils, the top soil has little or no humus. The subsoil is a mixture of sand, clay, minerals and salts. In the grassland, the roots of native plants penetrate deep in the ground, forming a dense sod (turf) that holds moisture and prevents erosion, and adds large amount of organic material to soil each year. In temperate forest soils, the top horizon is a rich mixture of humus and inorganic soil components [Fig. 16.7(a)]. In tropical rain forests, dense clay subsoil, heavy rainfall, and high temperatures result in nutrient-poor and shallow soils [Fig. 16.7(b)].



(a)



(b)

Fig. 16.7 *Comparison of soil profile (a) temperate deciduous forests, (b) tropical rain-forests*

Soil properties **:** Soils are made up of four components. The two solid substances are small mineral particles and organic matter. The small mineral particles come from weathering of rocks. The organic matter is of plant and animal origin, both from dead and living organisms. In an average soil, about 45 per cent of the volume is filled with mineral particles and about 5 per cent by organic matter. The other 50 per cent of the volume is filled with air and water. The amount of air or water varies greatly, depending on how wet the soil is at that time.

The proportion of mineral particles of different sizes in soil represents its texture. Mineral particles in soil vary greatly in size. Those between 0.2 and 2 mm are called **coarse sand**, 0.02 and 0.2 mm **fine sand**, 0.002 and 0.02 mm **silt**, and those less than 0.002 mm **clay**. Fine textured soils have a predominance of clay and silt particles, and coarse textured soils are predominated by sand particles.

Soil organic matter : The organic matter stored in soil comprises two fractions : (i) freshly dead and partially decomposed plant and animal material, called **detritus** or **litter**; (ii) colloidal, amorphous and dark coloured substance, called **humus**. Apart from the dead organic matter, soil harbours very large number of organisms, which include detritus feeders (e.g., termites, earthworms, carpenter ants and crabs), bacteria and fungi. The soil organisms play an important role in decomposition of plant and animal residues.

Fire

Humans have used fire to manipulate the environment to their own advantage since the dawn of history. Fire has marked effects on the physical environment through removal of the plant cover, burning of litter mass present on the soil surface, and loss of nutrients due to volatilisation.

Biotic Factors

The living species may be the producers (e.g., green plants) of food or consumers.

including herbivores, predators, parasites or omnivores. Species may have positive, negative or neutral effect on population growth and well-being of other species.

Range of Tolerance

Biological species show a range of tolerance to environmental factors. These factors vary in their effects, and any one which is present in least amount may become limiting. For example, low temperature limits plant growth at higher elevations; water availability limits plant growth in deserts; and low phosphorus availability limits the growth of phytoplankton in deep lakes. However, not only 'too little' of something is a limiting factor, but also 'too much' may limit the growth and distribution of an organism. The response of an organism to a range or gradient of a single environmental factor (temperature, sunlight or nutrient concentration) shows a bell-shaped curve (Fig. 16.8). The organisms are abundant in the central optimum range, showing greatest fitness, growth and survival. In the zone of stress, only a few organisms survive and are not able to reproduce. Organisms are absent from the zone of intolerance. Thus, the range between 'too little' and 'too much' is the range of tolerance, which determines the existence and abundance of an organism. Organisms are widely distributed if they have wide range of tolerance, and restricted distribution if the tolerance range is narrow.

Acclimatisation

The tolerance limits and optimal range of distribution may vary seasonally in some animals. If some environmental factor shifts beyond the tolerance range of an organism, the organism can come to the resting stage or migrate, or it can acclimatise. The gradual physiological adjustment to slowly changing

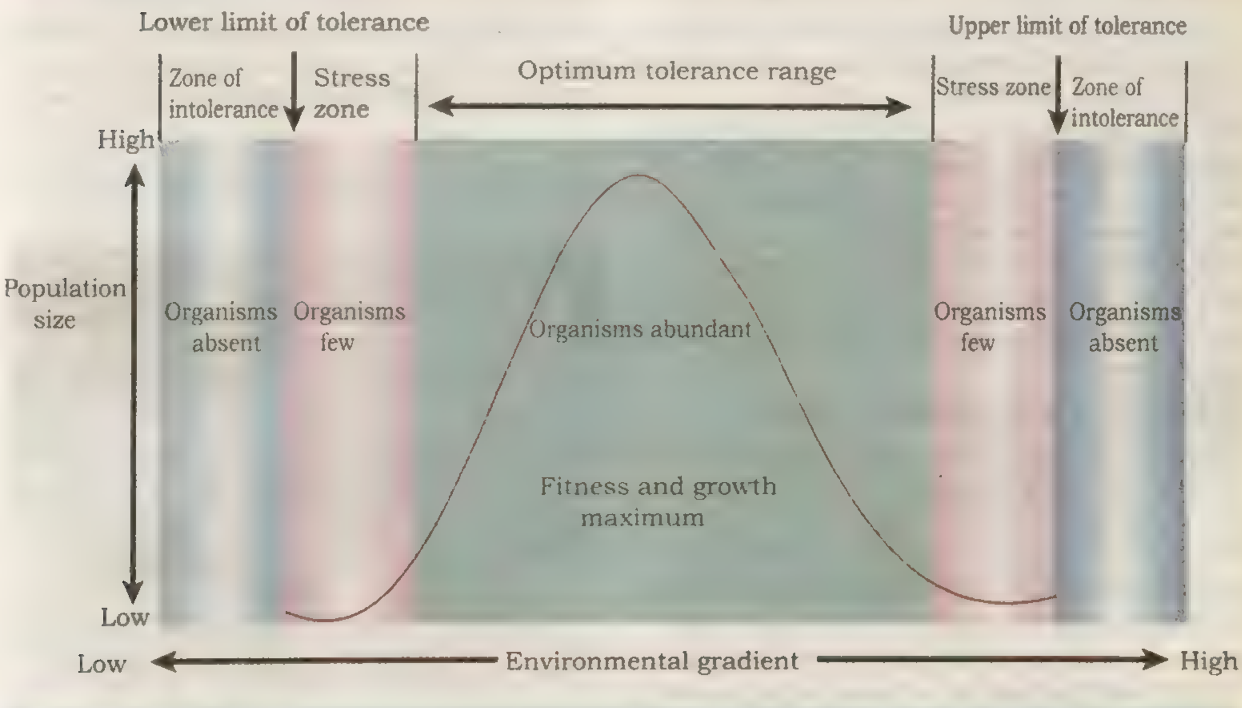


Fig. 16.8 *The response of an organism to a range or gradient of an environmental factor, (temperature, light, nutrient)*

new environmental conditions is known as acclimatisation.

16.4 Ecological Adaptations

The special characteristics of plants and animals that enable them to be successful under prevailing set of environmental conditions, are called **adaptations**. The organisms in natural world exhibit various types of morphological, physiological and behavioural adaptations. These special features have evolved over a long period of time, through the process of natural selection. The ultimate aim is to seek food and space the organisms need for their survival. The adaptive traits provide mechanism for many organisms to live and thrive in different types of ecosystems and habitats.

Phenotypic Plasticity and Ecotypes

The phenotype is the physical expression of the interaction between genotype of an organism and its environment. The phenotypes show variations due to differences in the environmental conditions within the local habitat. Such variation among individuals, produced by the influence of the local conditions of the habitat, is known as phenotypic plasticity. Usually, species having a wide range of distribution evolve genetically adapted local populations, called **ecotypes**. Ecotypes differ from each other on the basis of morphological and physiological characters. Although ecotypes of a species differ genetically, they are interfertile.

Strategies of Adaptations in Plants

Plants have special traits that help them to enhance their tolerance limits to light regimes, dry conditions, high temperature, water-saturated conditions and saline environments. In plants, flowers have evolved special structures to ensure pollination by insects or other animals. Plants have developed various mechanisms to deal with stress conditions of the environment.

Adaptations to light regime : Individual plants, as well as plant communities, adapt to different light intensities by becoming shade tolerant (**sciophytes**) or sun adapted (**heliophytes**). Heliophytes are adapted to high intensity of light, and have higher temperature optima for photosynthesis, as well as have high rates of respiration. The shade adapted plants generally have low photosynthetic, respiratory, and metabolic activities. Plants such as ferns and several herbaceous plants growing on the ground under the dense canopy of trees, are shade tolerant plants.

Adaptations to water scarcity and heat : Plants of hot deserts are adapted to survive in dry conditions of soil and high temperatures. The plants which have a short life span are known as **ephemerals**. For example, in desert areas of Rajasthan, many annual plants germinate from seeds, complete their life cycle quickly during the rainy season. Some plants have deep tap roots, which can reach even up to water table, in arid climates, and therefore, are capable of absorbing water from deep soil. Some prominent examples of plants having deep root systems are *Prosopis* (mesquite), palms and some species of *Acacia*.

Fig. 16.9 *Cacti and succulents adapted to hot conditions* *(Courtesy : Navtej Singh)*

In xerophytes, small leaves, sunken stomata, leathery leaf surfaces and waxy cuticle help in reducing transpiration.

As in the case of cacti and succulents, the presence of fleshy leaves and stems to store water (**succulence**) is an adaptation to dry environments (Fig. 16.9). In cacti, leaves are reduced to spines, whereas stems are modified into fleshy and spongy structures. Some cacti have expandable stems for storing water, and have spreading root systems in the surface layer of the soil.

Many tropical plants, particularly grasses which grow in hot and arid climates, possess C_4 pathway of photosynthesis. As you have learnt in Chapter 3, plants having this pathway perform better in low soil water environments. Such plants, therefore, use less water to achieve higher rates of photosynthesis, particularly at higher temperatures. Many desert plants, such as cacti and succulents, close their stomata during the day and open them in the night to reduce transpiration. You know from Chapter 3 that such plants possess CAM pathway of photosynthesis. Many xerophytes may accumulate proline (an amino acid) in response to stress. The heat shock proteins (chaperonins) provide physiological adaptations to plants to high temperatures. These proteins help other proteins to maintain their structure and avoid denaturisation at high temperatures.

Adaptations in aquatic environments : Plants which remain permanently immersed in water are called **hydrophytes**. They may by submerged, or partly submerged and show the presence of aerenchyma (large air spaces) in the leaves and petioles. **Aerenchyma** helps to transport oxygen produced during photosynthesis and permits its free diffusion to other parts. These tissues also impart buoyancy to the plants. Presence of inflated petioles in *Eichhornia* (water hyacinth) keeps the plants floating on the surface of water. Roots are poorly developed or absent in free floating hydrophytes like *Wolffia*, *Salvinia*, *Ceratophyllum* and *Hydrilla*. *Nymphaea* is an example of an emergent and rooted hydrophyte, which is seen growing in a pond (Fig.16.10). This plant, as well as other emergent hydrophytes (having leaves projecting above water surface), have a continuous system of air passages, which help the submerged plant organs to exchange gases from the atmosphere through the stomata in the emergent organs.

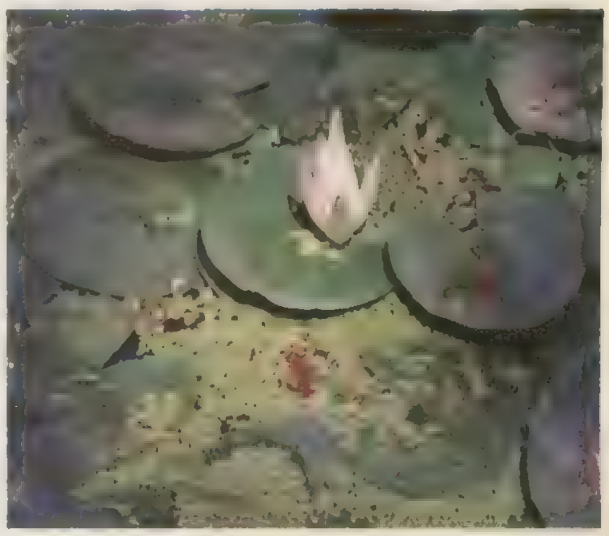


Fig. 16.10 *Nymphaea and other hydrophytes growing in a pond* (Courtesy : Navtej Singh)

Adaptations in saline environments : Halophytes are plants of saline environments, which are adapted to grow in high concentration of salt in soil or water. Halophytes occur in tidal marshes and coastal dunes, mangroves and saline soils. The halophytic plants, under hot and dry conditions, may become succulent and dilute the ion concentration of salts with water they store in cells of stems and leaves.

Mangroves are found in marshy conditions of tropical deltas and along ocean edges. Some species of mangroves can excrete salts through the salt glands on the leaves. Some mangroves

can exclude salts from the roots by pumping excess salts back into soil. For coping with conditions of high salt concentration and osmotic potential, many mangrove plants have high levels of organic solutes, such as proline, and sorbitol. *Dunaliella* species (green and halophytic algae found in hyper saline lakes) can tolerate saline conditions by accumulating glycerol in the cells, which helps in osmoregulation.

Avicennia and *Rhizophora* (red mangrove) are dominant species in mangrove forests. Since halophytes are exposed to saline and anaerobic conditions in wetlands, they have developed special adaptations, like pneumatophores, prop and stilt roots, and vivipary (seeds germinate while on the tree), etc. The presence of pneumatophores (the respiratory roots) helps to take up oxygen from the atmosphere and transport it to the main roots. Prop and stilt roots, in many species of mangroves, give support to the plants in wet substratum. Vivipary permits plants to escape the effect of salinity on seed germination.

Adaptations to oligotrophic soils : The oligotrophic soils contain low amounts of nutrients. These soils generally develop in old and geologically stable areas, such as soils found in much of the tropical rain forest region. Due to intense weathering and high rates of leaching, these soils have a poor nutrient retention capacity. In nutrient-poor soils, nutrient accumulation in vegetation is high. Many plants growing in nutrient-poor soils possess **mycorrhizae** which have mutualistic association of roots with fungi. Mycorrhizae help in efficient absorption of nutrients (e.g., phosphorus). Mycorrhizae are of two types, **endomycorrhizae** and **ectomycorrhizae**. In endomycorrhizae, the fungal hyphae dwell inside roots. These types of mycorrhizae are found in many vascular plants. In ectomycorrhizae, the fungal mycelium forms a mat outside the root. Ectomycorrhizae occur in several tree and shrub species in temperate regions.

Strategies of Adaptations in Animals

Like plants, animals also adjust to different environmental conditions to survive and flourish. Carnivores and herbivores have adaptations to eat a certain kind of food. Some animals have adaptations to avoid being eaten by the predators; others have behavioral adaptations to attract a mate. The males of some animals (particularly the plumage of the birds) have bright colouration, which gives advantage in sexual selection and mate attraction. However, a majority of animal adaptations to environmental variations and stress conditions are physiological and behavioural, as summarised in Tables 16.1 and 16.2. Some of these adaptations are described below.

Migration : Migration involves long-distance or short distance movement of animals from one

Table 16.1 : Migration as a Strategy of Adaptation in Animals

Type of migration	Examples	Activities
Long-distance	Arctic tern	Nests close to north pole in summer; flies south to Antarctica in autumn; returns to north pole again each spring.
Short-distance	Many birds	Birds migrate by using sun, moon, stars or magnetic field for direction and navigation.
	Caribou, elk and whales	Migrate in search of food each winter to warmer places.
Periodic	Locust	Large populations migrate in search of feeding grounds.

region to another. Many organisms that fly or swim, undertake extensive migrations. Activities of migration exhibited by some animals are given in Table 16.1. Arctic terns are sea birds that make a round trip of thousands of miles between their North Atlantic and the Arctic breeding grounds to the Antarctica every year. In Africa, wild beasts migrate long distances, following a geographical pattern of seasonal rainfall and availability of fresh vegetation. Locust migrates in search of new feeding grounds from the food depleted areas, in large numbers in the arid regions.

Camouflage : In some animals, the capacity to blend with surroundings or camouflage is a common adaptation. Some insects, reptiles and mammals have markings on their bodies, which make it difficult to distinguish them from shadows and branches, or from other members of the group.

Hibernation and aestivation : In very cold or dry environments, animals incapable of migration shift to a physiological dormant state. Spending winter in dormant condition is called hibernation. On the other hand, spending the dry-hot period in an inactive state is known as aestivation (examples are in Table 16.2).

Mimicry : Two species resemble each other closely, one species, called the mimic, is palatable to its predators, but resembles another species, called the model, which is distasteful to the predator. In ***Batesian*** **mimicry**, the mimic is defenseless, but has anti-predatory marks, like the model which has a defense against predators; hence, the mimic is able to protect itself from the attack of the predator. Similarly, the monarch butterfly (containing poison, toxic to predator) is mimicked by the viceroy butterfly (containing no poison). ***Mullerian*** **mimicry** is the process when the mimic shares the same defensive mechanism as the model.

Warning colouration : Concealing form and colouration enables a species to avoid its natural predator. The brightly coloured and highly poisonous dart frogs (*Phyllobates bicolour*; *Dendrobates pumilio*) of the tropical

Table 16.2 : Behavioural Strategies of Adaptations in Animals

Type	Examples	Processes and activities
Hibernation	Northern ground squirrels	True hibernators go into sleep during winter; body temperature drops; breathing and heartbeat become slow.
Aestivation	Ground squirrels in south-west deserts	Avoids heat by spending dry-hot period in a torpid (inactive) state into burrows.
Cryptic appearance (camouflage)	Leaf-like grasshopper (*Arantia rectifolia*) Praying mantis (*Phyllocrania paradoxa)*	Grasshopper resembles the complete leaf, or appears to be a part of leaf. Mimics a dead leaf and resembles background vegetation.
Batesian mimicry	Monarch butterfly and the mimic viceroy butterfly	Monarch butterfly (contains toxins in the body) and mimicked by viceroy butterfly (contains no toxins).
Mullerian mimicry	Monarch butterfly and the mimic queen butterfly	Both butterfly species look similar and are also distasteful.
Echolocation	Horseshoe bat	Produce high frequency sounds; detect the presence of the echoes produced from the objects on the same principle of sonar.

rain forests of South America are easily recognised and avoided by the predators.

Adaptations to water scarcity : Two types of adaptations are prominent in animals living in arid regions, viz. lowering of water loss as much as possible, and adapting to arid conditions. For example, the kangaroo rat conserves water by excreting solid urine, and can live from birth to death without even drinking water. The camels show unique adjustments to desert conditions, being very economical in water use, tolerant to wide fluctuations in body temperature, and are able to maintain blood stream moisture even during extreme heat stress.

Adaptations to cold : Sessile animals, such as barnacles and molluscs, living in very cold inter-tidal zones of northern shores, and several insects and spiders resist the effect of cold spells by a process known as cold hardening. The freeze tolerant organisms have ice nucleating proteins, which induce ice formation in the extracellular spaces at very low sub zero temperatures. Some freeze-avoiding animals can tolerate environmental temperatures below 0°C by accumulating glycerol or antifreeze proteins that lower freezing point of their body fluids. Presence of such antifreeze compounds allows the fish in Antarctica region to remain active in sea water.

SUMMARY

Ecology is defined as the study of reciprocal relationships between organisms and their environment. The levels of biological organisation of interest in ecology are : Organism – Population – Community – Ecosystem – Biosphere. The community contains many organisms of different species. An ecosystem includes biological community, integrated with its physical environment. Biosphere includes all ecosystems on the earth. The prevailing regional environment has large-scale effects on climate, biota and vegetation. Microclimate represents the climatic conditions closer to living organisms. Habitat is the place where an organism lives, whereas niche is the functional role of an organism.

Light and temperature affect climate, activities of plants and animals, and metabolic processes of organisms. Water vapour in the atmosphere, evaporation and precipitation regulate the hydrological cycle. Soil plays an important role in plant growth by providing water, nutrients and anchorage, and a habitat for diverse populations of soil organisms.

Factors generally limiting the activities of terrestrial organisms are moisture and temperature; those affecting aquatic organisms are mainly oxygen and light. Organisms with broad range of tolerance have wide distribution; narrow range results in restricted distribution of organisms.

Desert plants adapt to water scarcity by mining water with deep tap root system, storing water in succulent leaves and stems, and having low transpiration. Plants adapt to high concentration of salt in soil or water by salt excretion, salt exclusion, or by accumulating organic solutes in stems and roots. The oligotrophic soils are nutrient-poor soils. In such soils, nutrient retention is high in vegetation and mycorrhizae help in mineral nutrition of plants.

A majority of animal adaptations are physiological and behavioural which include migration, regulation of body temperature, and mimicry to

avoid predators. In *Batesian* mimicry, the mimic is defenseless. In the case of *Mullerian* mimicry, the mimic shares the same defensive mechanisms as the model. Some organisms avoid predation by cryptic appearance or warning colouration. In cold environments, organisms adapt by super cooling their body fluids, or by lowering the freezing point of their body fluids by antifreeze compounds.

EXERCISES

1. The ecological levels of organisation, in terms of complexity, are arranged in the order ____________________.
2. The kangaroo rat and camel adapt to dry and hot conditions in the deserts by ______________.
3. The role of an organism in the ecological system is known as :
   (a) Habitat (b) Herbivory
   (c) Niche (d) Interaction
4. Adaptation to low temperature and freezing in animals occurs due to the production of :
   (a) Antifreeze proteins (b) Chaperonins
   (c) Proline (d) Analine
5. What is the difference between climate and weather?
6. Distinguish between camouflage and mimicry?
7. How do plants adapt to oligotrophic soils?
8. Define the following terms :
   (a) Migration (b) Stratosphere
   (c) Community (d) Biosphere
9. Explain the following terms :
   (a) Mimicry (b) Acclimatisation
   (c) Ectotherms (d) Endotherms
10. Describe environmental factors and their importance to plants and animals.
11. Explain how tolerance to environmental factors determines distribution of species.
12. How do plants adapt to water scarcity and saline environments?
13. What are the different types of adaptations in animals? Explain with suitable examples.

Chapter 17

Population, Biotic Community and Succession

In the previous chapter, you have learnt about the factors of physical environment and their influence on the organisms. You also know that the organisms adapt to different environmental conditions for survival and successful living. The organisms in a habitat are not there simply by chance; their presence and suitability to a particular environment reflects a long-drawn struggle for survival. The individuals of a species living within a habitat constitute a population. In natural conditions, we find populations of a variety of plants, animals and micro-organisms living together within a habitat. All such populations together constitute the **biological** (biotic) **community** of the habitat. This chapter deals with population and community levels of organisation, population characteristics and growth, species interaction in the community, and change in community over time.

17.1 Population

The term 'population' has been interpreted differently in different areas of study. In human demography, a population is a set of humans in a given area, like a village, town, state or country, or even all humans inhabiting the planet Earth. In genetics, a population is a group of interbreeding individuals of the same species, which is isolated from other such groups. Populations of different species are not capable of breeding with each other because of various types of biological (e.g., breeding behaviour, inability to form fertile hybrids) and physical barriers (e.g., habitat and geographical isolation).

In ecology, a population is a group of individuals of the same species, inhabiting the same area, and functioning as a unit of biotic community. For example, all individuals of the common grass, *Cynodon*, in a given area constitute its population. A group of snails of the same species present in a given area represent a population. Similarly, all pine trees occurring in a habitat, constitute a population. Organisms in a population undergo the same life cycle. They experience similar ecological processes at a particular stage of the life cycle. Populations can be defined at various spatial scales. Local populations can occupy very small habitat patches, like a temporary pool of water. A set of local populations connected by dispersing individuals is called a **metapopulation**. Populations can also be considered at the scale of regions, islands, continents or oceans. Even the entire species can be viewed as a population.

Population Characteristics

Populations have a number of attributes. Different populations can be compared by measuring these attributes. To understand changes in population size, we measure population density, spatial distribution of organisms, and the factors regulating population growth. A population has group characteristics, like density, natality (birth rate), mortality (death rate), dispersal, age distribution (ratio of one age group to the other), biotic potential and growth forms.

Density : The size of the population is represented by its density. Density is expressed as the total number of individuals present per

Fig. 17.1 *Age structure of hypothetical populations which are expected to increase, remain stable, or decline with the passage of time*

unit area or volume at a given time. For example, 50 individuals of a tree species may occur per hectare, or 70 individuals of the grass *Cynodon* per square metre. Density of plants is determined by counting individuals in sampling units of predetermined sizes. Census or counting is done for human population in India every ten years. Species density varies from time to time and from one area to another. You often find greater density of plants during rainy season, compared to dry season. The size of the population is determined by available resources, like nutrients, water, etc., at a given time and other group properties, such as natality, mortality and age structure.

Natality : The increase in number of individuals in a population under given environmental conditions is called natality. Birth, hatching, germination and, even vegetative propagation, cause increase in number of individuals. When the increase in individuals is expressed per unit time, it is called natality rate.

Mortality : The loss of individuals due to death in a population under given environmental conditions is termed mortality. It is expressed as mortality rate, indicating number of individuals dying over a time-period.

Dispersal : The majority of organisms disperse at one time or the other during their life cycles. The individuals move into (immigration) and move out of the population (emigration), and these movements affect the size of the population.

Age distribution : Various age groups in a population determine its reproductive status. The three ages referred to as ecological ages in a population are prereproductive, reproductive and postreproductive. Distribution of age groups influences the population growth. Populations with more young members grow rapidly, while the declining populations have a large proportion of older individuals (Fig. 17.1). The age structure in a population is also linked to births and deaths.

Biotic potential and environmental resistance : The inherent maximum capacity of an organism to reproduce or increase in number is termed **biotic potential** (designated by the symbol '*r*'). Biotic potential is realised only when the environmental conditions are non-limiting, so that natality rate is maximum and mortality rate is minimum. Under these conditions, population size increases at the maximum rate. However, nature keeps a check on the expression of biotic potential. For example, if a pair of flies is allowed to reproduce unchecked, the fly population may outweigh the earth in a few years. The environmental check on population size, or its biotic potential, is called **environmental resistance**. With increase in population size, the environmental resistance (against that population) tends to increase. The environmental resistance represents the limiting effect of abiotic (e.g., water, space) and biotic factors (e.g., food, competition) that do not allow organisms to

attain their biotic potential and keep the population size at a much lower level.

Population Growth

The growth of a population can be measured as increase in its size over a period of time. Let us assume that a population having the initial size, N_0, increases to size, N_t, after time interval, t. Then, the change in population size is given by the expression :

$$N_t = N_0 + B + I - D - E$$

where, N_0 = size of population at the beginning of change, B = natality rate, I = rate of immigration (individuals coming in), D = mortality rate, and E = rate of emigration (individuals moving out).

Population Growth Forms

Populations have characteristic patterns of growth with time. These patterns are known as **population growth forms**. There are two basic population growth forms, designated as J-shaped and S-shaped. In the case of J-shaped growth form, the population grows exponentially, and after attaining the peak value, the population may abruptly crash [Fig. 17.2(a)]. The exponential growth cannot be sustained infinitely because not only environment is ever changing, food and space are limited. For example, many insect populations show explosive increase in numbers during the rainy season, followed by their disappearance at the end of the season. The J-shaped growth form is represented by the following exponential equation :

$$\frac{dN}{dt} = rN$$

where, dN/dt is the rate of change in population size, r is the biotic potential, and N is the population size.

S-shaped or sigmoid growth form shows an initial gradual increase in population size, followed by an exponential increase and then a gradual decline to a near-constant level. This slow-down following the exponential phase, occurs due to increasing environmental resistance. In such cases, plotting of the rate of increase of population over time gives an S-shaped or sigmoid curve [Fig. 17.2(b)].

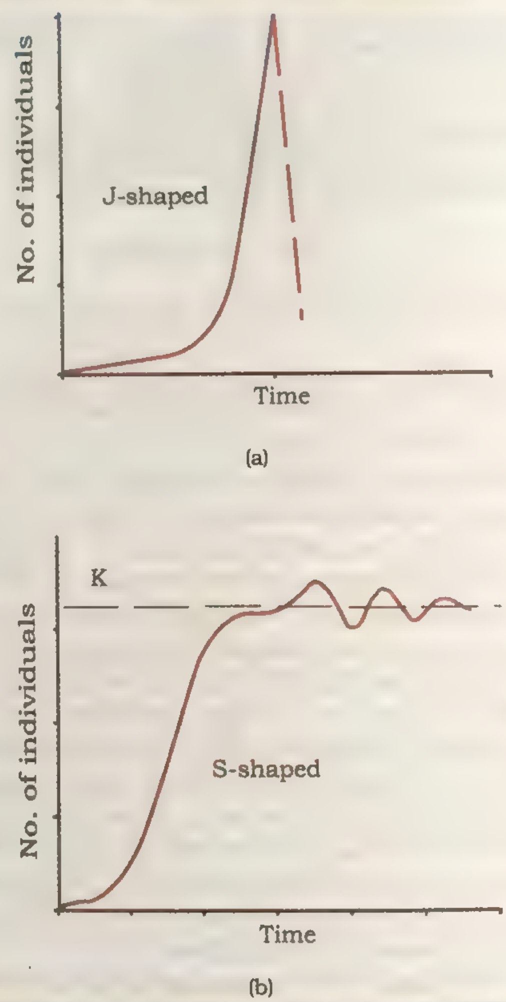


Fig. 17.2 *Population growth forms : (a) J-shaped, (b) S-shaped. K represents the carrying capacity*

Generally, the population size stabilises with time, with minor fluctuations around this upper limit. The maximum number of individuals of a population that can be sustained indefinitely in a given habitat, represents its **carrying capacity** (K). The S-shaped sigmoid growth form is represented by the following equation, which includes an expression for environmental resistance :

$$\frac{dN}{dt} = rN\left(\frac{K-N}{K}\right) = rN\left(1-\frac{N}{K}\right)$$

where dN/dt, r and N are the same as in the equation for J-shaped growth form, and $(K\text{-}N)/K$ or $1\text{-}(N/K)$ stands for environmental resistance.

17.2 Ecological Interdependence and Interactions

Species Interdependence

Members of the biotic community in an area are dependent on one another. The interdependence is reflected in their interactions, mainly for food, space, reproduction and protection. These interactions are important for survival of different species and the community as a group. Food interactions are reflected in trophic structure (food chains), which comprises plants, animals and micro-organisms.

Plants and animals have well established interdependence for reproduction. It is best illustrated by the role of insects in the community. The insects are flower-specific and have structures suitable for nectar sucking and pollination. On the other hand, flowers may also be insect-specific. Snapdragon flower, for example, has lip-like petals to facilitate insect entry and landing. Both flowers and insects have developed and evolved in a way leading to their interdependence. Flowers offer nectar to insects as a reward for pollination. The fluctuations in insect population of a community would affect pollination, thereby affecting plant reproduction. The use of insecticide in a crop field may kill bees, and consequently crop pollination may be reduced. Birds and mammals help in the dispersal of seeds and fruits. The interdependence in the community can be further demonstrated with the example of cuckoo laying eggs in the nest of other birds, and gall wasps embedding their eggs deep into the tissues of plants to ensure hatching and protection.

Some members of the biotic community, particularly the animals, develop certain protective mechanisms to avoid or to check the enemies. The weaker members sometimes camouflage to avoid detection. You will find that butterflies and moths have colours matching the flower colours to make their detection difficult. The camouflage can be easily observed in praying mantis and leaf insect (Fig. 17.3), which even mimic the shapes of leaves and branches.

Fig. 17.3 *Camouflage exhibited by praying mantis (left) and leaf insect (right)*

You can also observe orchids mimicking the butterflies, as far as colours are concerned. It has been observed that generally, weaker members, especially among the animals, mimic the strong, fast moving species and those having a fewer natural enemies. For example, non-poisonous snakes mimic the poisonous ones to scare away the enemies. Birds mimic voice or song of other animals. The nature of mimic action could be both defensive as well as offensive.

Species Interactions

The interactions between populations of species in a community are broadly categorised into **positive** (beneficial) and **negative** (inhibition) **interactions**, depending upon the nature of effect on the interacting organisms (Table 17.1).

Table 17.1 : Interactions between Populations of Different Species in the Biotic Community

Type of interaction	Species A	Species B	Nature of interaction
Mutualism	+	+	Beneficial to both A and B
Commensalism	+	0	Beneficial to A and no effect on B
Parasitism	+	–	Beneficial to A (parasite) and harmful to B (host)
Predation	+	–	Beneficial to A (predator) and inhibiting B (prey)
Competition	–	–	Adverse effect on both A and B

0 indicates no effect on species; + positive effect on species; – negative effect on species.

Interactions with Positive Effect

Some of the interactions between species in the community benefit one or both the species. Mutualism and commensalism are examples involving beneficial interactions.

Mutualism : An association of two species, in which both species are benefited, is called mutualism. Mutualism may or may not involve close physical association between the individuals of pairs of species. The condition in which there is a close physical association between the individuals of a pair of species is also called **symbiosis** (= living together). Mutualism is a functional association, not merely living together. Mutualism may be obligate (species are completely dependent upon each other) or facultative (one species may survive even in the absence of the other partner species). Mutualism is exemplified by the nitrogen fixing bacteria (*Rhizobium*) living in root nodules of legumes, where the bacteria, deriving nutrition from the host plant, fix atmospheric nitrogen and make it available to the plants. Algae and fungi exhibit mutually beneficial relationship in lichens (Fig. 17.4). The fungi provide protection to algae, and the latter prepares food for the fungi. In the case of coral reef, coelenterates and algae live in obligate relationship. Mycorrhizae are mutualistic relationship between fungi and roots of about 80 per cent of higher plants. The fungus helps in mineral nutrition of the plants with which they are associated and obtains, in turn, carbohydrates from plants. Bacteria in the gut of some animals (cattle) help in cellulose digestion.

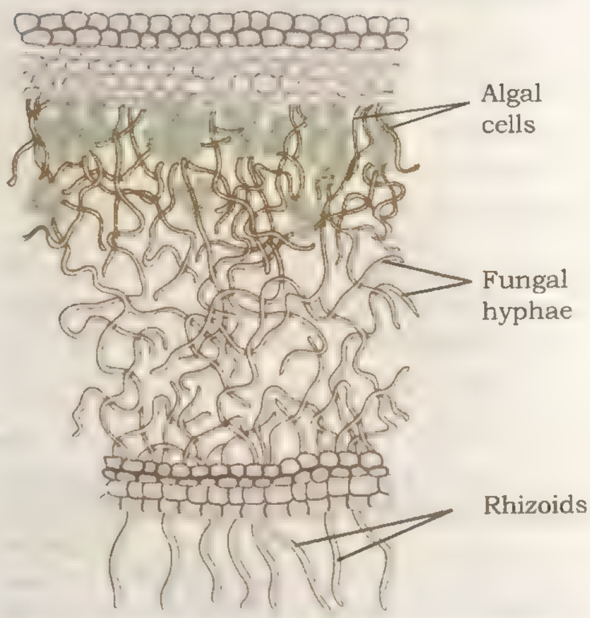


Fig. 17.4 *Section of a lichen showing the arrangement of algal and fungal partners*

Facultative mutualism can be illustrated with the example of sea anemone, which gets attached to the shell of hermit crab (Fig. 17.5). The sea anemone grows on the back of the crab,

Fig. 17.5 *Crab and sea anemone mutualism; sea anemone gets attached to the back of a hermit crab*

providing camouflage and protection (the sea anemone has stinging cells) and, in turn, the sea anemone is transported for reaching new food sources. This type of mutualism is also called **protocooperation.**

Commensalism : It is a relationship between two species where one species is benefited, while the other neither gets any benefit, nor is adversely affected under normal conditions. Some organisms live inside the bodies of larger animals in order to protect themselves from the enemies and adverse environment.

Commensalism can be illustrated with the example of sucker fish and shark (Fig. 17.6). The sucker fish attaches to shark surface with the help of its dorsal fin, which is modified into a hold fast. The sucker fish is dispersed to distant areas with better food supply. Besides, the fish gets protection from predators due to its association with shark. However, the shark does not get any benefit from sucker fish and it is also not affected adversely.

Fig. 17.6 *Commensalism between sucker fish and shark*

Epiphytes (e.g., mosses, ferns, orchids, money plant) growing on trees benefit from better light conditions, but generally, they do not harm the tree. Several woody climbers take the support of the trees for exposing their canopy aboveground without doing any harm to the tree itself. These relationships are also considered examples of commensalism.

Interactions with Negative Effects

Certain interactions between different species result in negative effect on either or both species. Parasitism and predation are interactions when one species gains and the other suffers. But, in the interaction involving competition, both species are harmed.

Competition: Interaction between two species, where both suffer adverse effects, is known as competition. Usually, competition occurs when resources, such as space, light and nutrients, etc. are in short supply. As a result of competition, the growth and seed production of both species is reduced.

Competition is basically of two types : (i) interspecific, and (ii) intraspecific. **Interspecific competition** occurs between individuals of two different species occurring in a habitat. On the other hand, **intraspecific competition** occurs between individuals of the same species. Generally, the intraspecific competition is more intense than interspecific competition. The requirements of individuals of the same species are very similar; hence, they compete more fiercely.

Predation : Interaction between species involving killing and consumption of prey is called predation. The species which eats the other is called the **predator**, and the one consumed is termed the **prey**. Predation is commonly illustrated by the herbivore-carnivore interaction, grass-deer-tiger food chain. For example, tiger, the predator, keeps check on deer (prey) population. If the predator population increases, it consumes more prey, thereby reducing the population of prey. The reduction in prey population may reduce the population of predator, resulting from starvation and emigration. The reduction in predator population may lead to increase in prey population, since they are not preyed upon. The increased prey population may over-graze the grasses, and the shortage of herbage may eventually lead to reduction in prey population. It may ultimately affect population of predators. Thus, these relationships stabilise the prey and predator populations in a community.

Parasitism : In the interaction called parasitism, the species smaller in size (the parasite) lives in or on the larger species (host) from which it obtains food. Parasitism also involves shelter, in addition to food obtained by a parasite. Plants like *Cuscuta* (dodder), *Loranthus Viscum*, (Mistletoe) and *Rafflesia* are parasitic plants, which live on other flowering plants.

Parasites may alter the population growth of hosts, shorten the life cycle, weaken the host, and drastically reduce the reproduction to the extent of causing sterility.

The parasites which remain outside the host are called **ectoparasites**, or external parasites (e.g., ticks, mites and lice). They generally attach to the skin and hair of the hosts. Some of them use suckers, clamps, adhesive surface, cutting, biting, sucking mouth parts, or root-like outgrowth for consuming host-tissues. Parasites like leeches, lice, ticks, mites, feed on the body fluids of the hosts. The hosts also develop defensive mechanisms to protect themselves from the parasites, as in the case of limbless hosts.

Parasites, like the predators, limit the population of the host species, but they are generally host-specific, and do not have choice or alternatives like predators. They are smaller in size and have higher biotic/reproductive potential compared to the predators. Parasites have poor means of dispersal and require specialised structures to reach or invade the host. Predators, on the other hand, are quite mobile and capable of capturing the prey. The newly acquired predators and parasites are often more damaging than the older ones, since the latter are familiar and the species getting affected have adjusted.

17.3 Biotic Community

Biotic community organisation results from interdependence and interactions amongst populations of different species in a habitat. Large number of biotic communities are found in nature due to : (i) existence of diverse habitats with characteristic environmental conditions, and (ii) co-occurrence of different species whose tolerance ranges overlap with the environmental conditions obtained in that habitat. When similar habitat conditions are repeated at another location, the same biotic community gets established there. Each biotic community possesses ecological characteristics which differentiate it from other communities. Major community characteristics are described below.

Community Characteristics

Species composition : The kinds of plants and other organisms present in a community indicate its species composition. The species composition differs from one community to another. Even in the same community, there may be seasonal variation in plant species.

Dominance : Only one or few species in a community are in sufficient abundance (having high density) to dominate and influence other species in terms of numbers and biomass production. They also determine animal distribution. For example, in terrestrial communities, generally the species of tall trees are dominants. Communities are generally named after their dominant species. For example, a forest community in which pine trees are dominant is called a pine forest. Grassland represents a community which has

grass species dominating over the other herbaceous species. Communities are also named after important environmental factors, such as desert community with dry conditions, and marine communities occurring under saline conditions of the oceans.

Physiognomy and stratification : A community is first noticed by its physiognomy. **Physiognomy** refers to the external appearance or "look" of the community. The external appearance is the total effect created by the combination of vertical structure and architecture of dominant species of vegetation. For instance, the high physiognomy of a forest differs markedly from a low physiognomy of a grassland. However, several communities may have similar physiognomy, yet they differ sharply on the basis of species composition and dominants (e.g., different forest types).

Stratification of a community depicts vertical layering of the vegetation. Different layers are occupied by different species. The vertical stratification provides physical structure to the plant community, in which many forms of plant and animal life are adapted to live in. A well developed forest ecosystem exhibits a highly stratified structure, consisting of several layers of vegetation. These layers include the canopy, the understorey tree layer, the shrub layer and the herb layer. Similarly, a pond community has surface dwellers and bottom dwellers. Vertical stratification leads to increase in number of species and to efficient use of resources of a habitat by different types of plants. In aquatic ecosystems, stratification from surface to bottom is determined by light penetration, temperature profile and oxygen profile.

Species diversity : Some communities, such as tropical rain forest and coral reef community, show high species diversity with many different kinds of species living at each trophic level. In other communities, like a desert, there may be relatively few species in the entire community. Species diversity includes the total number of species present in a community and the relative abundance of these species. Diversity is recognised as an important functional attribute of biotic community. You will study several diversity-related aspects in Chapter 20.

Keystone and link species : The species having much greater influence on community characteristics, relative to their low abundance or biomass, are called **keystone** species. These species play a vital role in controlling the relative abundance of other species. Removal of keystone species causes serious disruption in the functioning of the community. For example, in the tropical rain forests, the different species of figs are the keystone species as these produce large quantity of fruits. During the time of food scarcity, these fruits are eaten by monkeys, birds, bats and other vertebrates. Thus, by protecting the fig trees, the animals dependent on them are also conserved.

Only a few species work as keystone species, and several others work as critical **link** species. Mycorrhizal fungi in soil are critical link species as they establish essential links in the absorption of nutrients from the soil and organic residues. Some critical link species may also provide food for the network species; others play important roles as pollinators of flowers or dispersal agents of seeds and fruits. Tropical rain forests are rich in critical link species due to high degree of animal-dependent pollination and dispersal.

Ecotones and edge effect : The transition zone between two communities is known as **ecotone**. For example, the ecotone between grassland and the forest. Ecotone contains few species from both communities. The total number of species is often greater in the ecotone than in the adjoining communities. The tendency of increased variety and density of some organisms at the community border is known as **edge effect**. The organisms which occur primarily, or most abundantly, or spend the greatest amount of their time in junctions between communities, are called **edge species**.

Analysis of Plant Communities

Analysis of community characters is generally done for : (a) recording variations within and between communities, and (b) naming and classifying communities. Community analysis involves measurements of various characters in sample plots (also

called **quadrats**) located randomly within the community. Measurements made in sample plots are appropriately processed to reflect the characteristics of the entire community. Various community characters can be categorised as :

(i) **Analytic characters**, which are directly observed or measured in sample plots.

(ii) **Synthetic characters**, which are derived from the measurements of analytic characters.

The analytic characters may be either qualitative or quantitative. Qualitative analytic characters are based on non-quantitative observations; for example, the species composition and stratification of vegetation. On the other hand, quantitative analytic characters, as the name suggests, are measured. The major quantitative analytic characters are :

(i) **Frequency** (based on percentage of plots in which a species is present, indicating its dispersion in space).

(ii) **Density** (number of individuals per unit area, indicating the relative abundance of a species).

(iii) **Diversity** (Total number of species in a unit area, including plants, animals and microbes).

(iv) **Cover** (percentage land area occupied by a species, indicating the influence zone of a species; cover is expressed as basal cover, area occupied by stem bases, or crown cover, the area covered by canopy).

(v) **Biomass** (quantity of living materials per unit area, indicating the growth of a species; see more details on biomass and productivity in Chapter 18).

(vi) **Leaf size** (percentages of species having different leaf sizes, indicating the adaptation of the vegetation to the prevailing environment).

Synthetic characters (e.g., presence and constance) reflect the pattern of distribution and performance of different species through all the locations where the community occurs.

17.4 Succession

The biotic communities are dynamic in nature and change with the passage of time. The successive replacement of communities in an area over a period of time is known as **ecological succession.** Both abiotic and biotic components are involved in such change. Succession is a community-controlled phenomenon, which results due to the action and co-action on living organisms. Physical environment often determines the nature, direction, rate and optimal limit of change.

During succession, changes occur both in plant and animal communities. The plant succession, however, is easily visible. Two basic types of succession can be distinguished. Succession occurring on previously unoccupied sites, such as a rock outcrop or glacial moraine, is called **primary succession**. The more common type of succession is the secondary succession, which occurs in an area where the natural vegetation has been destroyed or removed. For example, the forests destroyed by fire and excessive lumbering may be reoccupied by herbs in the initial stages. The reappearance and establishment of communities in such areas is called **secondary succession**.

The plants that invade the bare land initially, are called **pioneer species**. The assemblage of pioneer species forms the **pioneer community**. Generally, the pioneer species show high rate of growth but short life span. In time, the pioneer community is replaced by another community with different species combination. This second community is replaced by a third community, and so on. The different communities or stages represented by combinations of mosses, herbs, shrubs and trees replacing one another during succession are referred to as **seral stages** or seral communities. The plant species which get established later, during the course of succession, are known as **late successional species**. These species are slow growing and long lived. The terminal stage of succession is represented by the **climax community.** The climax community is stable and does not show changes in species composition, as long as the environmental conditions remain the same. The sequence of communities succeeding each other during the course of succession represents the **sere**.

The succession occurring in water bodies like ponds and lakes is called **hydrarch succession**, and the succession taking place in terrestrial areas with low moisture (for example, rock, sand) is known as **xerarch**. These two types of succession are described below.

Succession on a Bare Rock (Xerarch)

Lower plants, like lichens, form a crust over the bare rocks and begin to form soil from their organic remains and by stimulating chemical breakdown of the rocks. Lichens are normally followed by mosses, which speed up the process of soil accumulation by trapping wind-blown particles. Mosses grow in bunch, and together with lichens, make a mat over the substratum. Lichens and mosses, which get established on barren rock, are the pioneer species forming the pioneer community. The accumulation of soil particles in the lichen-moss carpet provides suitable substratum for the germination of seeds of herbaceous plants which are dispersed in it. The seeds of higher plants germinate and grow successfully in pockets of newly formed soil on the rock (Fig. 17.7). Gradually, more soil is accumulated and herbaceous species make way for the invasion of shrubs followed by trees. The dead shoots and fallen leaves accumulate and enrich the soil. Passing through the seral stages in course of time, climax community gets established. Depending upon the climatic conditions and extent of soil formation, the climax community is generally dominated by trees. The changes in biotic community from the pioneer to the climax stage may take hundreds of years.

Fig. 17.7 *Xerarch succession on bare rock*

Succession in Aquatic Environment (Hydrarch)

Ecological succession also occurs in water bodies like ponds and lakes. Water bodies are prone to silting as a result of soil erosion from surrounding areas. Blockage of rivers by landslides and construction of dams lead to formation of new lakes on land where hydrarch succession sets in due to invasion of aquatic species (Fig. 17.8). In a pond, the phytoplankton and zooplankton constitute the pioneer community. Submerged aquatic plants, with their roots anchored in the mud, are next to colonise the pond. The dead

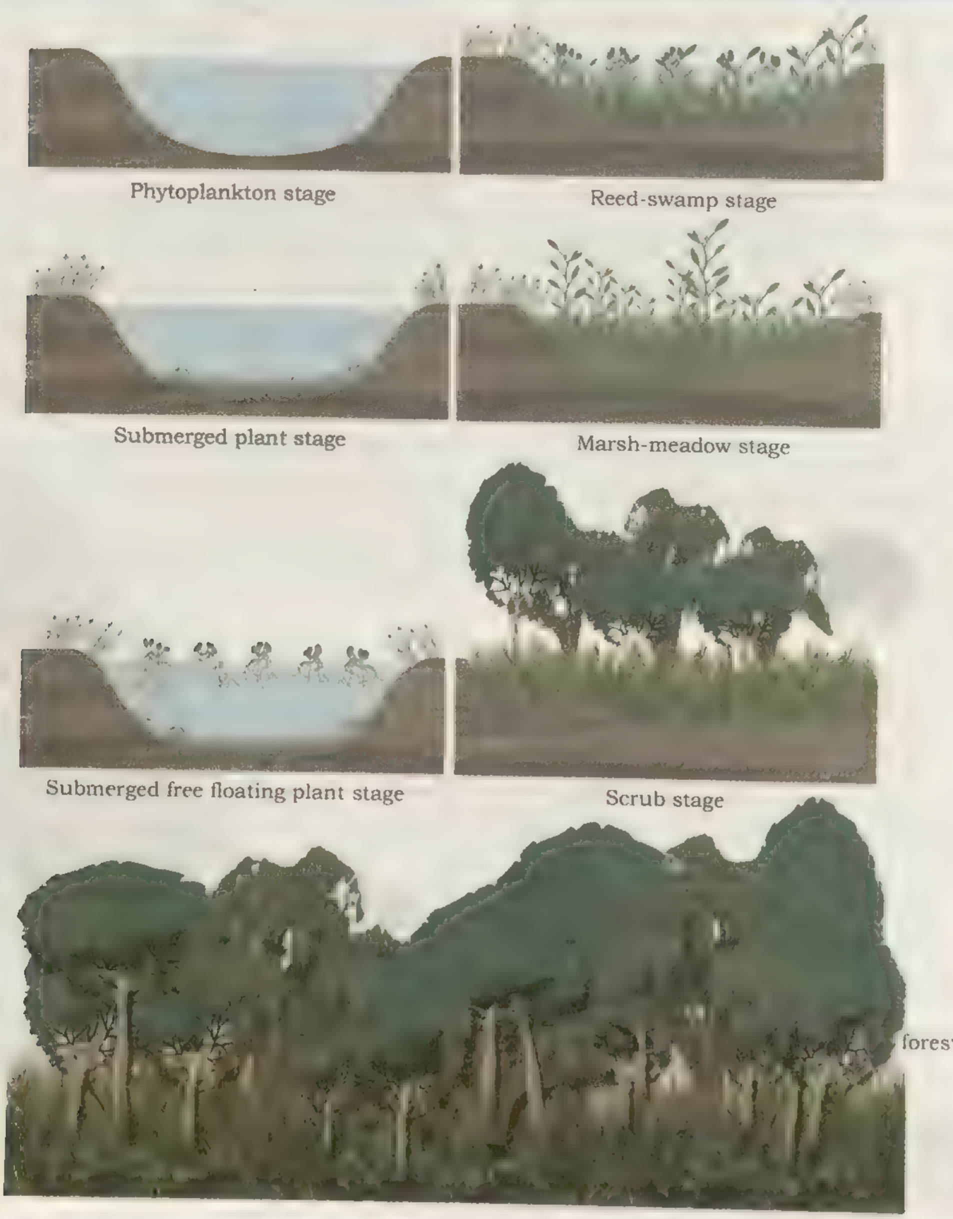


Fig. 17.8 *Hydrarch succession in a pond*

remains of these organisms settle at the pond bottom. Besides, floating plant species invade the pond. With the continued siltation, the pond bottom is gradually raised and water layer becomes shallow and rich in nutrients. As a result, rooted, emergent plants with aerial leaves, such as reeds, are able to colonise the pond. This is accompanied by the invasion of Dragon flies, crustaceans and more rooted species of plants. Thus, the species composition of the pond keeps changing with time. With increased settling of silt and deposition of dead organic matter derived from floating and rooted species, the pond becomes shallower until it gets transformed into a terrestrial habitat. Ultimately, terrestrial species, like grasses, bushes and trees, colonise the pond area and a climax community is established. The colonisation by land plants usually progresses from margins toward the centre of the pond area.

Changes in Community Characteristics and Climax

The exact sequence of species and communities that appear during primary or secondary succession, varies with the habitat conditions. The seral stages differ from late successional or climax stages with reference to structure and functions (Table 17.2). The average size of individuals generally increases and the community organisation becomes more complex in the climax community as compared to the seral community. The food webs become complex during successional stages. The efficiency of energy use and nutrient conservation increase as the community progresses towards the climax stage.

Table 17.2 : Ecosystem Characteristics that Change during Succession

Characteristics	**Stages**	
	Seral	**Climax**
Community structure		
Size of individuals	Small	Large
Ecological niches	Few, generalised	Many specialised
Community organisation	Simple	Complex
Community functions		
Food chains and food web	Simple	Complex
Efficiency of energy use	Low	High
Nutrient conservation	Low	High

The species composition at the climax stage is determined by the regional climate, as well as local conditions of soil, topography and water availability. The climax stage reflects the highest level of vegetation and the associated fauna that can be supported under the given environmental conditions.

SUMMARY

Population is a group of individuals of the same species inhabiting the same area. The members of the population are capable of interbreeding among themselves. A population is characterised by parameters like density, natality, mortality, age distribution, biotic potential, growth form, etc. Under favourable conditions, the population size tends to increase. Broadly speaking, two patterns of growth form occur, the J-shaped and S-shaped. The population size is determined by the balance between number of individuals added (by natality and immigration) and individuals removed (by mortality and emigration). The maximum size of the population that can be supported in a given habitat is called its carrying capacity.

Populations of different species occurring in a habitat comprise the biotic community. The biotic community can be recognised and named through features like dominance, stratification and species interactions. Community analysis involves measurements of analytic (both qualitative and quantitative) and synthetic characters. Quantitative analytic characters include frequency, density, cover, biomass and leaf size of species present in the community. The transition zone between two communities is referred to as ecotone.

The members of the community are interdependent for food, reproduction and protection. The insects play an important role in pollination of plants. Interactions between members of the biotic community have positive or negative effects. Organisms living together may benefit each other (mutualism), or one may benefit without affecting the other (commensalism). Sometimes, one organism (predator) may adversely affect the other (prey). Parasitism is the relationship in which the smaller organism (parasite) adversely affects the larger host.

The biotic community is dynamic and undergoes changes with the passage of time. These changes are sequentially ordered and constitute succession. Succession involves replacement of one community by the other. Succession begins with invasion of the barren area by the pioneer species, which later, make way for other species. Ultimately, succession leads to a climax community. The climax community remains stable as long as environment remains unchanged.

EXERCISES

1. Distinguish between population and community.
2. Why the members of a population do not breed with other populations?
3. Explain J-shaped pattern of population growth.
4. Compare J-shaped pattern with S-shaped pattern of population growth.
5. Define biotic community. How is it different from the term 'community' used in human population?
6. Fill in the blanks :
   (a) The aggregation of individuals of species is called ___________.
   (b) The relationship where one organism is benefited, while the other is neither benefited nor harmed, is referred as _______.
   (c) Organisms preying on animals are called ___________.
   (d) An association of two species in which both species are benefited is called _______________.
7. How is a biotic community named? Give examples.
8. Select the statement which best explains commensalism.
   (a) One organism is benefited.
   (b) Both the organisms are benefited.
   (c) One organism is benefited; other is not affected.
   (d) One organism is benefited; other is affected.

9. Community is defined as aggregation of :
   (a) Individuals of the same kind.
   (b) Individuals of different kinds.
   (c) Individuals of a population.
   (d) Populations of different species.
10. Parasite can be explained as an organism which depends on others :
   (a) for food;
   (b) for shelter;
   (c) for both food and shelter; and
   (d) for reproduction.
11. How do you distinguish the following?
   (a) Ecotones and Edge effect
   (b) Keystone species and Critical Link species
   (c) Ectoparasite and Endoparasite
   (d) Primary succession and Secondary succession
   (e) Pioneer community and Climax community.
12. What are the important analytic characteristics in community analysis?
13. Give any example of mimicry in organisms.
14. Write some special characteristics of a parasite.
15. Explain how predation is beneficial in the long run.
16. Describe the process of succession on a bare rock.
17. How does succession differ in terrestrial and aquatic systems? Give salient points.
18. Explain the differences between the seral stage and the climax community during succession.

Chapter 18

Ecosystem : Structure and Function

We have learnt in Chapter 16 that ecosystems are parts of nature where living organisms interact amongst themselves and with their physical environment. The term **ecosystem** was coined by Sir Arthur Tansley in 1935. Ecosystems vary greatly in size, such as a small pond or a large forest. Ecosystems can be recognised as self-regulating and self-sustaining units of landscape. In nature, two major categories of ecosystems may be distinguished: terrestrial and aquatic. Forests, grasslands, and deserts are examples of terrestrial ecosystems. The aquatic ecosystems can be either freshwater (ponds, lakes, streams), or salt-water (marine, estuaries) type.

Human activities may modify or convert natural ecosystems into anthropogenic or man-made ecosystems. For example, natural forests have been cut and the land converted to tree plantations or agricultural systems. Often, dam construction involves submergence of forests and conversion to water reservoirs. Spacecrafts and aquariums may also be considered as man-made ecosystems. In this chapter, you will learn the basic concepts of ecosystem, structure and function related to productivity, energy flow, decomposition, ecological efficiencies and nutrient cycling. The general characteristics of major terrestrial biomes will also be described.

18.1 Ecosystem Components

An ecosystem has two basic components : (i) abiotic (non-living), and (ii) biotic (living organisms).

Abiotic components comprise inorganic materials (e.g., carbon, nitrogen, oxygen, CO_2, water, etc.) and dead organic matter containing proteins, carbohydrates, lipids, minerals, etc. Abiotic substances are present in soil, water and air. The climatic parameters like solar radiation and temperature determine the abiotic conditions within which the organisms carry out life functions.

Biotic components include producers, consumers and decomposers. **Producers** are the autotrophic (=self-nourishing), generally chlorophyll-bearing organisms, which produce their own food (high energy organic compounds) by fixing light energy in the presence of simple inorganic abiotic substances. A variety of photosynthetic bacteria, chemosynthetic bacteria and photosynthetic protozoa also produce organic substances in terrestrial and aquatic habitats, though in very small amounts. In terrestrial ecosystems, the autotrophs are usually rooted plants (herbs, shrubs and trees), whereas in deep aquatic ecosystems, floating microscopic plants called **phytoplankton** are the major autotrophs. In shallow waters rooted plants, **macrophytes**, are the dominant producers. When the environmental conditions are optimum, the phytoplankton may produce as much food as produced by the larger shrubs and trees on unit area (land or water surface) basis.

Consumers or **phagotrophs** (*phago* : to eat) are **heterotrophic** (=other feeding) organisms, mostly animals which generally ingest or swallow their food. The food of consumers consists of organic compounds produced by

other living organisms. A consumer which derives nutrition by eating plants is called primary consumer or **herbivore** (e.g., grazing cattle). The secondary consumer or **carnivore** is an animal that devours the flesh of herbivore or other animals.

Decomposers or **saprotrophs** (*sapro* : to decompose) are other heterotrophic organisms, consisting mostly of bacteria and fungi which live on dead organic matter or detritus. Unlike consumers, the decomposers do not ingest their food. Instead, they release different enzymes from their bodies into the dead and decaying plant and animal remains. The extracellular digestion of the dead remains, leads to the release of simpler inorganic substances which are then utilised by the decomposers.

Ecosystems can generally be physically delineated. But sometimes, ecosystems intergrate with each other. At large, spatial scale, all ecosystems are interconnected by flow of energy and transfer of materials with the neighbouring ecosystems, or even with distant ecosystems. For example, leaves of riverbank trees dropping in river water represent transfer of energy and material from terrestrial to aquatic ecosystem. Terrestrial birds diving to catch fish in water bodies, make similar transfers from aquatic to terrestrial ecosystems. Soil material may be eroded from a forest ecosystem and washed into the adjoining stream, or dust blown from a desert ecosystem may deposit over another ecosystem located miles away.

18.2 Ecosystem Structure and Function

Structure

Biotic and abiotic components are physically organised to provide a characteristic structure of the ecosystem. Important structural features are : **species composition** and **stratification.** Some ecosystems (e.g., tropical rain forests) show tall plant canopy and a bewildering number of biological species. On the other hand, the desert ecosystem shows a low, discontinuous herb layer consisting of fewer species and extensive bare patches of soil.

Another way to depict the ecosystem structure is through food relationships of producers and consumers. Trophic (food) structure of ecosystem is based on the existence of several trophic levels in the ecosystem. The producers form the first trophic level, herbivores the second, and carnivores constitute the third. Trophic structure may be described in terms of the amount of living material, called **standing crop**, present in different trophic levels at a given time. The standing crop is commonly expressed as the number or biomass of organisms per unit area. The biomass of a species is expressed in terms of either fresh or dry weight. Dry weight is preferred to avoid variations in weight due to seasonal moisture differences in biomass.

Nutrients necessary for the growth of living organisms are accumulated in the biomass and in abiotic components like soil. The amounts of nutrients, such as nitrogen, phosphorus and calcium present in the soil at any given time, is referred to as the **standing state**. The standing states of nutrients differ from one ecosystem to another, or with seasons even in the same ecosystem.

Function

Ecosystems possess a natural tendency to persist. This is made possible by a variety of **functions** (activities undertaken to ensure persistence) performed by the structural components. For instance, green leaves function as sites of food production, and roots absorb nutrients from the soil. Herbivores perform the function of utilising part of the plant production, and in turn, serve as food for carnivores. Decomposers carry out the function of breaking down complex organic materials into simpler inorganic products, which can be used by the producers. These functions are carried out in the ecosystem through delicately balanced and controlled **processes**. For example, the process of photosynthesis is involved in food production, and that of decomposition, leads to release of nutrients contained in the organic matter.

A knowledge of the rates at which different processes occur in ecosystem is necessary to understand the interrelations of ecosystem

structure and function. The key functional aspects of the ecosystem are :

(i) Productivity and energy flow;
(ii) Nutrient cycling; and
(iii) Development and stabilisation.

18.3 Productivity

The rate of biomass production is called productivity. Productivity in ecosystems is of two kinds, primary and secondary. **Primary productivity** refers to the rate at which sunlight is captured by producers for the synthesis of energy-rich organic compounds through photosynthesis. Productivity is a rate function, and is expressed in terms of dry matter produced or energy captured per unit area of land, per unit time. It is generally expressed in terms of g m^{-2} $year^{-1}$, or kcal m^{-2} $year^{-1}$. Hence, the productivity of different ecosystems can be easily compared. Primary productivity has two aspects, gross and net. The total organic matter (biomass) production is called **gross primary production**. However, while the energy capture process is operating in the green tissues, these as well as other tissues, are consuming photosynthates in respiration. The balance energy or biomass remaining after meeting the requirement of respiration of producers, is called **net primary productivity**, as shown below.

Net productivity = Gross productivity – respiration

The net primary productivity results in the accumulation of plant biomass, which serves as the food of herbivores and decomposers. At the trophic level of consumers, the rate at which food energy is assimilated, is called **secondary productivity**. It should be recognised that the food of consumers has been produced by the primary producers, and secondary productivity reflects only the utilisation of this food for the production of consumer biomass.

The magnitude of primary productivity depends on the photosynthetic capacity of producers and the prevailing environmental conditions, particularly solar radiation, temperature and soil moisture. In tropical regions, primary productivity may be sustained throughout the year, provided adequate soil moisture remains available. However, in temperate regions, primary productivity is severely limited by cold climate and a short snow-free growing period during the year. Table 18.1 shows plant biomass and net primary productivity of major ecosystems of the world. High level of net primary productivity (>20 t ha^{-1} $year^{-1}$) has been recorded for mature tropical rain forests. Deserts generally fall in the lowest productivity category (<1 t ha^{-1} $year^{-1}$).

In aquatic ecosystems, productivity is generally limited by light, which decreases with increasing water depth. In deep oceans, nutrients often become limiting for productivity. Nitrogen is regarded as the most

Table 18.1 : Geographical Area, Mean Plant Biomass and Net Productivity in Major World Ecosystems

Ecosystems	Area (10^6 km^2)	Mean plant biomass (t ha^{-1})	Mean net primary productivity (t ha^{-1} $year^{-1}$)
Tropical rain forest	17	440	20
Tropical deciduous forest	8	360	15
Temperate deciduous forest	7	300	12
Temperate coniferous forest	12	200	8
Savanna	15	40	9
Temperate grassland	9	20	5
Desert shrub	18	10	0.7

t = ton = 1000 kg
ha = 10,000 m^2

important nutrient limiting productivity in marine ecosystems.

18.4 Decomposition

While productivity involves synthesis and building processes, equally important is decomposition, which concerns breakdown of complex organic matter by decomposers to inorganic raw materials like carbon dioxide, water and various nutrients. The upper layer of soil is the main site for decomposition processes in the ecosystem.

Dead plant parts and animal remains are called **detritus**. Dried plant parts, like leaves, bark, flowers, etc., and dead remains of animals, including faecal matter, drop over the soil and constitute the **aboveground detritus** (also known as **litter fall**). The **belowground detritus** is primarily composed of dead roots (also called **root detritus**). With the passage of time, decomposing detritus loses weight, until it disappears completely. If decomposition is retarded or stopped, large amounts of partially decomposed organic matter shall accumulate in the ecosystem.

Decomposition Processes

As shown in Figure 18.1, decomposition involves several processes. These processes can be categorised as fragmentation of detritus, leaching and catabolism.

(i) The **fragmentation of detritus,** mainly due to the action of detritus feeding invertebrates (**detritivores**), causes it to break into smaller particles. The detritus gets pulverised when passing through the digestive tracts of animals. Due to fragmentation, the surface area of detritus particles is greatly increased.

(ii) Water percolating through soil removes soluble substances (e.g., sugars, several nutrients) from the fragmented detritus due to **leaching** action.

(iii) The extracellular enzymes released by bacteria and fungi carry out **catabolism**, i.e., enzymatic conversion of the decomposing detritus to simpler compounds and inorganic substances. It is important to know that all the three decomposition processes operate simultaneously on the detritus.

Humification and **mineralisation** occur during decomposition in the soil (Fig. 18.1). Humification leads to accumulation of a dark-coloured amorphous substance, called **humus**. Humus is highly resistant to microbial action and undergoes extremely slow decomposition. It serves as a reservoir of nutrients. Mineralisation results in the release of inorganic substances (e.g., CO_2, H_2O) and available nutrients (NH_4^+, Ca^{++}, Mg^{++}, K^+ etc.) in the soil.

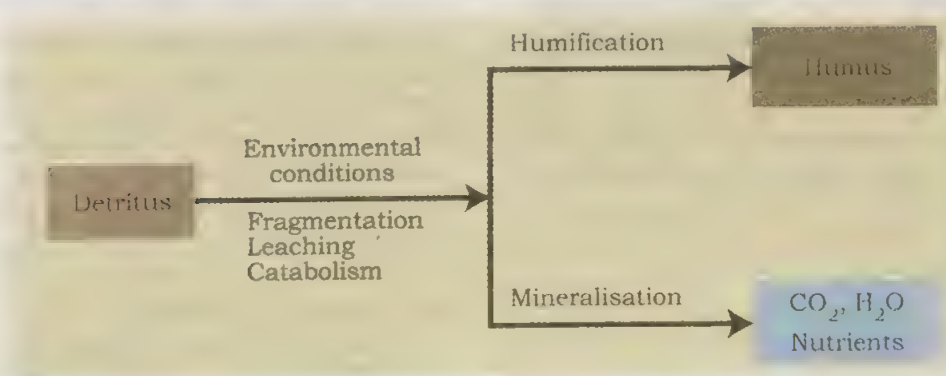


Fig. 18.1 *Processes involved in decomposition of detritus*

Under certain conditions, soil nutrients get tied up with the biomass of microbes and become temporarily unavailable to other organisms. Such incorporation of nutrients in living microbes is called **nutrient immobilisation**. Nutrients remain immobilised for variable periods and get mineralised later, after the death of microbes. This immobilisation prevents the nutrients from being washed out from the ecosystem.

Factors Affecting Decomposition

The rate of decomposition of detritus is primarily regulated by the climatic factors and the chemical quality of detritus. Amongst climatic factors, the key role is played by temperature and soil moisture through their regulatory effect on the activities of soil microbes. Detritus decomposes very rapidly, within a few weeks or months, in a climate characterised by higher temperature (>25°C) and moist conditions (e.g., in humid tropical regions). Low temperature (<10°C) sharply reduces decomposition rate even if moisture is in plenty. For example, in regions of high latitude or altitude, complete decomposition of detritus may require several years or decades. Decomposition rate is also low under prolonged soil dryness, even if the temperature remains high (e.g., in tropical deserts).

The accumulation of certain substances in the detritus either promotes or retards decomposition rate. The chemical quality of detritus is determined by the relative proportions of water-soluble substances (including sugars), polyphenols, lignin and nitrogen. Within the same climatic conditions, decomposition rate is slower if the detritus is rich in substances like lignin and chitin. The nitrogen-rich detritus, having low amounts of lignin, decomposes relatively rapidly. The actual rate of decomposition of detritus in natural conditions depends upon the integrated effect of environmental conditions and detritus quality.

18.5 Energy Flow

Energy flow is the key function in the ecosystem. The storage and expenditure of energy in the ecosystem is based on two basic laws of thermodynamics. In accordance with the **first law of thermodynamics** (which states that energy is neither created nor destroyed, but can be transferred from one component to another, or transformed from one state to another), energy of sunlight can be transformed into energy of food and heat. No energy transformation occurs spontaneously unless energy is degraded or dissipated from a concentrated to a dispersed form (**second law of thermodynamics**). Thus, in ecosystem, the transfer of food energy from one organism to another leads to degradation and loss of a major fraction of food energy as heat due to metabolic activities, with only a small fraction being stored in living tissues or biomass. While energy in food is in concentrated form, heat energy is highly dispersed. It must be understood that all changes in energy forms can be accounted for in any system.

It is useful to examine the relationship between incident radiant energy and the energy captured by the producers in the food they manufacture (Fig. 18.2). Only the visible light, or the **photosynthetically active radiation (PAR)**, which carries about 50 per cent of the energy of total incident solar radiation, is available to producers for absorption. By multiplying the estimated productivity with the **calorific value** (i.e., energy content per unit weight) of biomass, the energy captured can be determined. The calorific value is determined by burning known weight of dry biomass in a bomb calorimeter in the presence of oxygen, and measuring the heat evolved.

Under favourable environmental conditions, only about 1-5 per cent energy of incident radiation, or 2-10 per cent of PAR, is actually captured by the photosynthetic process (gross primary productivity), and the remaining portion is dissipated. Since the simultaneously occurring respiratory processes are energy consuming and use up part of the photosynthetic gain, the net capture of energy (net primary productivity) is reduced to only 0.8-4 per cent of the incident total radiation, or 1.6-8 per cent of PAR. Only the energy captured in net productivity of producers can be used by other trophic levels.

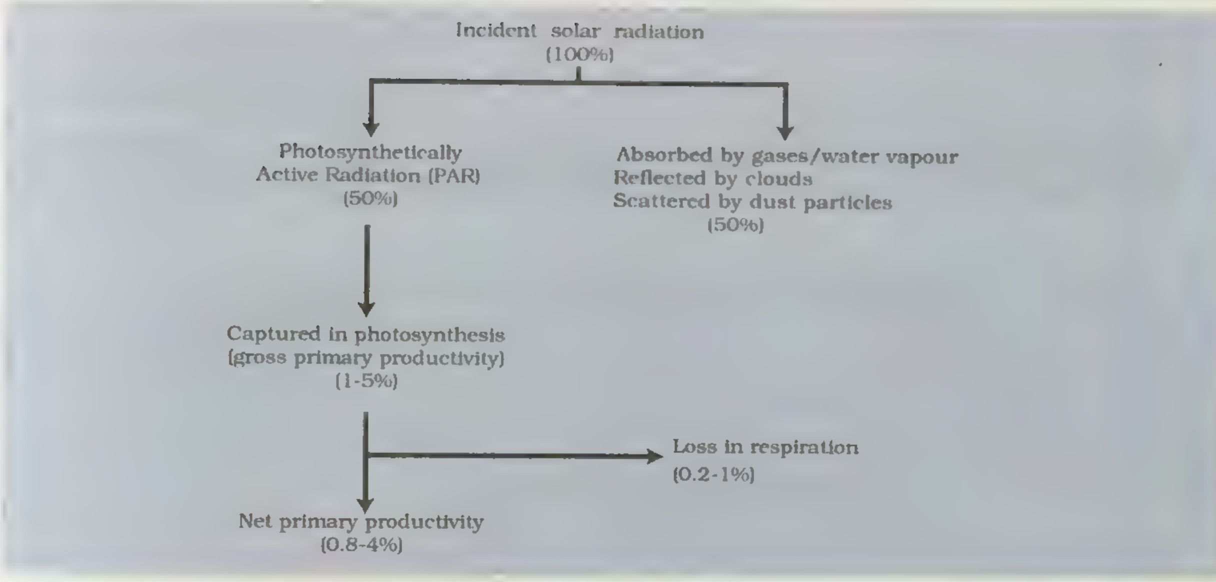


Fig. 18.2 *Fate of solar radiation incident on plant canopy (Values in parentheses represent fraction of incident solar radiation)*

Food Chain and Food Web

All trophic levels in an ecosystem are connected by transfer of food or energy. The transfer of energy from one trophic level (e.g., producers) to the next trophic level (e.g., consumers) is called **food chain**. Two types of food chains can be distinguished in all ecosystems, **grazing food chain** and **detritus food chain**. Grazing food chain extends from producers through herbivores to carnivores. Cattle grazing in grasslands, deer browsing in forest, and insects feeding on crops and trees, are most common biotic constituents of the grazing food chain. Detritus food chain begins with dead organic matter and passes through detritus-feeding organisms in soil to organisms feeding on detritus-feeders. A much larger fraction of energy flows through the detritus food chain. Different food chains are often interconnected, e.g., a specific herbivore of one food chain may serve as food of carnivores of several other food chains. Such interconnected matrix of food chains is called **food web**.

Energy Flow Model

A simplified representation of energy flow through ecosystem has been made in Figure 18.3. Two aspects with respect to energy flow in ecosystem need careful consideration. First, the energy flows *one way*, i.e., from producers through herbivores to carnivores; it cannot be transferred in the reverse direction. Second, the amount of energy flow decreases with successive trophic levels. Producers capture only a small fraction of solar energy (1-5 per cent of total solar radiation), and the bulk of unutilised energy is dissipated mostly as heat. Part of the energy captured in gross production of producers is used for maintenance of their standing crop (respiration) and for providing food to herbivores (**herbivory**). The unutilised net primary production is ultimately converted to detritus, which serves as energy source to decomposers. Thus, energy actually used by the herbivore trophic level is only a small fraction of the energy captured at the producer level. On an average, in different ecosystems, the herbivore assimilation or productivity approximates 10 per cent of gross productivity of producers.

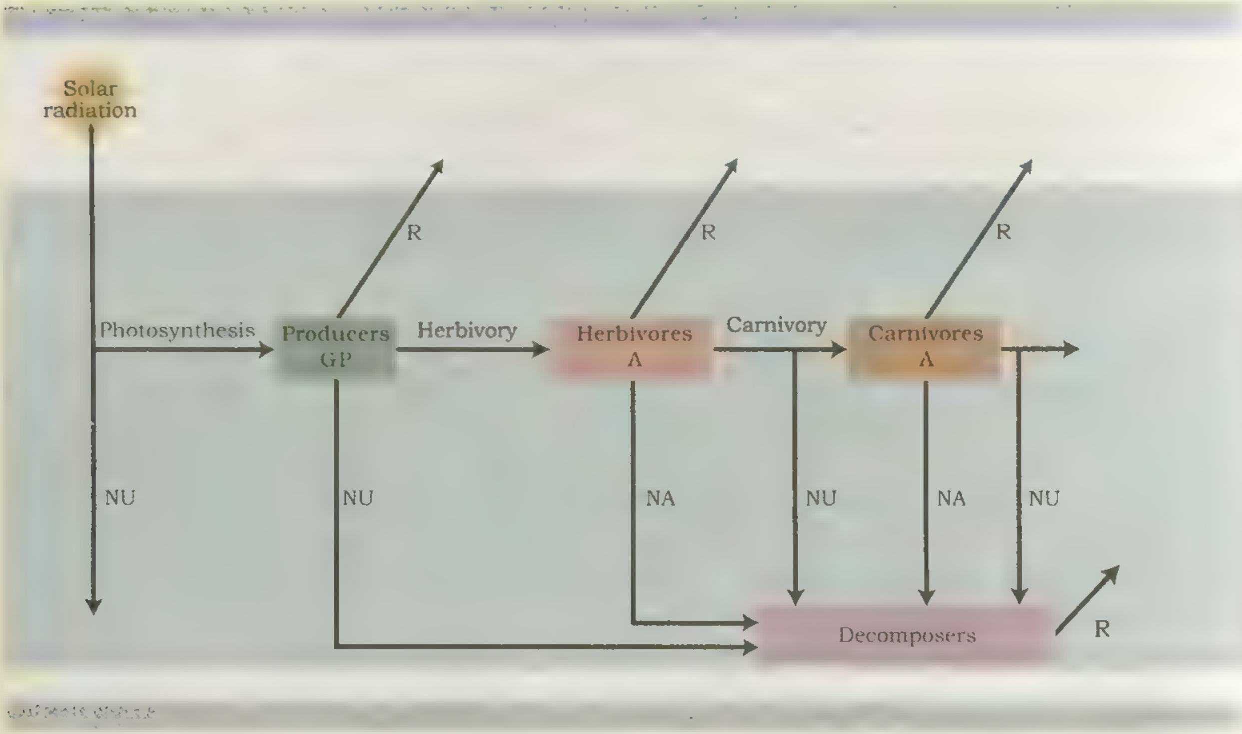


Fig. 18.3 *A generalised energy flow model of ecosystem : Boxes represent biotic components and the arrows show the pathways of energy transfer: SR, Solar radiation; GP, Gross primary productivity; A, Assimilation; R, Respiration; NU, Not utilised; NA, Not assimilated*

The energy assimilated by the herbivores is used in respiration and a fraction of unassimilated energy is transferred to decomposers (e.g., faecal matter). The remaining herbivore level energy is either utilised by the carnivores, or gets transferred to decomposers after the death of herbivores. Again, only a small fraction (about 10 per cent) of herbivore productivity is used to support carnivore productivity. Similarly, the energy available at carnivore trophic level is again partitioned, leaving a very small fraction to support the next trophic level (top carnivore).

The respiration cost also increases sharply along successive higher trophic levels. On an average, respiration of producer consumes about 20 per cent of its gross productivity. Herbivores consume about 30 per cent of assimilated energy in respiration. The proportion of assimilated energy consumed in respiration rises to about 60 per cent in carnivores. Because of this tremendous loss of energy at successive higher trophic levels, the residual energy is decreased to such an extent that no further trophic level can be supported. Therefore, the length of food chains in an ecosystem is generally limited to 3-4 trophic levels.

18.6 Ecological Pyramids

Trophic structure in ecosystem can be represented by comparing standing crop (either number of individuals, or biomass) or energy fixed per unit area at different trophic levels. Graphical representation of the trophic structure is done by drawing ecological pyramids, where the basal, mid and top tiers show the parameter values for producers, herbivores and carnivores in the ecosystem (Fig. 18.4). Common parameters used for constructing ecological pyramids are number of individuals (**pyramid of numbers**), dry weight (**pyramid of biomass**),

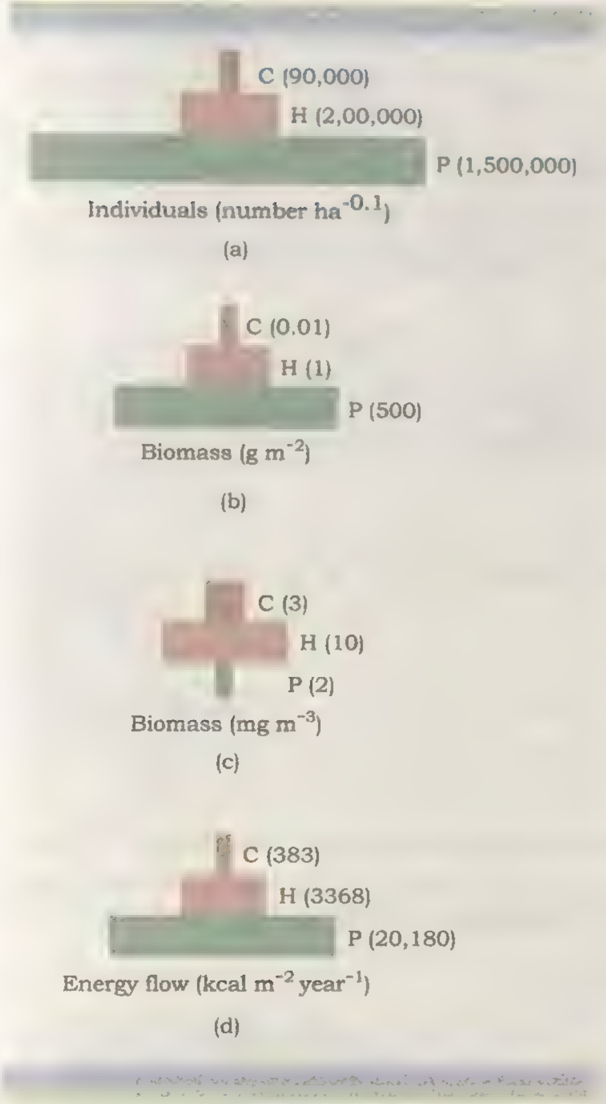


Fig. 18.4 *Ecological pyramids : (a) Pyramid of number in a grassland, (b) Pyramid of biomass in a fallow land, (c) Inverted pyramid of biomass in a lake, (d) Energy pyramid in a spring; P – Producer, H – Herbivore, C – Carnivore*

or rate of energy flow (**pyramid of energy**) at successive trophic levels.

In most ecosystems, the pyramids of number and biomass are upright, i.e., producers outnumber and outweigh the herbivores, and herbivores outnumber or outweigh the carnivores. However, in certain ecosystems, the pyramid of number (e.g., in tree-dominated ecosystems) and the pyramid of biomass (e.g., in deep water bodies) may look inverted. For example, numerous small insects may occur on a single tree, and in oceans, the combined weight of numerous small short-lived phytoplankton organisms at a given time is exceeded by the combined weight of large, long-lived fish. The pyramid of energy, however, is always upright. Amongst the three kinds of ecological pyramids, the pyramid of energy, which expresses mainly the rate of food production, can be considered most representative of the functional characteristics. It emphasises that total energy flow at successive trophic level always decreases, compared to the preceding trophic level (explanation : lesser energy flow at herbivore trophic level compared to producer trophic level, and so on).

18.7 Ecological Efficiencies

Various ratios are used to express the efficiency with which organisms exploit their food resources and convert the food into biomass. Commonly, such ratios are calculated by relating output to input of energy (both expressed in same units) at various points along pathways of energy flow. These ratios are multiplied with 100 to express the efficiency as percentage. At the level of producer, the **photosynthetic efficiency** and **net production efficiency** deserve consideration.

The photosynthetic efficiency measures the ability to utilise incident solar radiation. This efficiency is also expressed in relation to PAR. Net production efficiency varies widely amongst different species. Tree species having larger non-photosynthetic biomass (e.g., huge trunks and branches) show lesser net production efficiency. These efficiencies are computed as shown on page 268.

The ability of the herbivores and carnivores to use the food energy ingested, varies from one species to another. Important efficiency measures for consumers include **assimilation efficiency** (at one trophic level) and **ecological efficiency**, or **trophic level efficiency** (between two trophic levels).

$$\text{Photosynthetic efficiency} = \frac{\text{Gross primary productivity} \times 100}{\text{Incident total solar radiation}}$$

$$\text{Net production efficiency} = \frac{\text{Net primary productivity} \times 100}{\text{Gross primary productivity}}$$

$$\text{Assimilation efficiency} = \frac{\text{Food energy assimilated} \times 100}{\text{Food energy ingested}}$$

$$\text{Ecological efficiency} = \frac{\text{Energy in biomass production at a trophic level} \times 100}{\text{Energy in biomass production at previous trophic level}}$$

18.8 Nutrient Cycling

You have learnt in Chapter 2 on mineral nutrition that the living organisms require several chemical elements for their life processes. Plants can photosynthesise simple compounds like carbohydrates, using carbon, hydrogen and oxygen obtained from carbon dioxide and water; however, for the synthesis of more complex materials (e.g., proteins), they require supply of additional essential elements or nutrients. Some nutrients are required in large amounts (e.g., nitrogen and phosphorus), but several others are needed in trace amounts (e.g., zinc, molybdenum, copper, etc.). Nutrients may be used as part of the structural components or as components of enzymes which mediate various life processes.

Unlike energy which flows unidirectionally, nutrients are continually exchanged between organisms and their physical environment. **Nutrient cycles** involve storage and transfer of

Eugene P. Odum

(1913-2002)

Prof. Eugene P. Odum (1913-2002), widely recognized as the "father of ecosystem ecology", was the founder of the famous Institute of Ecology at the University of Georgia, and its research sites: the Savannah River Ecology Laboratory in Aiken, South Carolina, and the Marine Institute on Sapelo Island, Georgia, USA. His monumental book entitled *Fundamentals of Ecology* (first published in 1953) revolutionized teaching of ecology world over as it presented a new framework of the subject. He argued that ecology is an integrated discipline that assimilated other physical and biological sciences, and the earth is comprised of numerous inter-linked and self-perpetuating ecosystems which show a wide variety of structures and functional characteristics. These ecosystems process solar energy, cycle abiotic nutrients, and provide numerous services to mankind. In view of his outstanding services to the cause of ecology, Prof. Odum was elected Fellow of National Academy of Science USA. He received (jointly with his brother Prof. H.T. Odum) the prestigious Crafoord Prize of the Royal Swedish Academy, considered to be the equivalent of the Nobel Prize in Ecology.

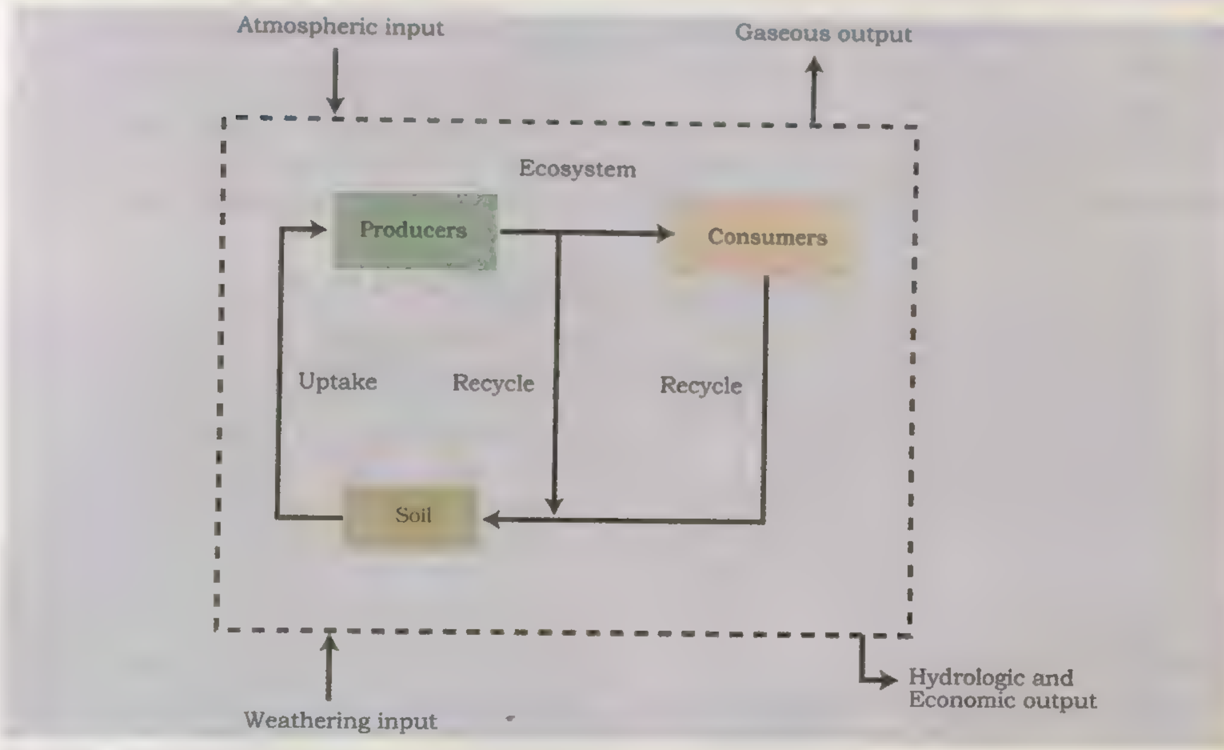


Fig. 18.5 *A generalised model of ecosystem nutrient cycling : Nutrients are brought in (input), moved out (output), and cycled internally in the ecosystem. Boxes represent ecosystem components and arrows show the pathways of nutrient transfers*

nutrients through various components of the ecosystem so that the nutrients are repeatedly used. Another term **biogeochemical cycle** (*bio* : living organisms, and *geo* : rocks, air and water), also denotes nutrient cycling. But biogeochemical cycle is generally considered in a regional or global context.

Bulk of nutrients are stored in abiotic reservoirs in relatively inactive state, and a smaller active fraction, often existing in ionic form, is involved in cycling. Nutrient cycles are of two types, the **gaseous** and the **sedimentary**. The reservoir of gaseous type of nutrient cycle is generally located in the atmosphere or the hydrosphere. But in the sedimentary type, the reservoir exists in the earth's crust. Nitrogen (reservoir in atmosphere) and phosphorus (reservoir in lithosphere) cycles are well-known examples of gaseous and sedimentary types, respectively.

Nutrient cycles can be conveniently considered under the following three aspects as shown in Figure 18.5.

Input of Nutrients

Ecosystem receives nutrients from external sources and stores them for further use through biological processes. For example, nutrients in dissolved state are gained from rainfall (**wet deposition**), or in particulate state from dust fall (**dry deposition**). Symbiotic biological fixation of nitrogen in soil also represents an input. Weathering of soil parent materials, which releases available nutrients from their fixed state, is another example of input.

Output of Nutrients

Nutrients are moved out of an ecosystem and many become input to another ecosystem. For example, considerable loss of nutrients like calcium and magnesium occurs through runoff water, or

through soil erosion. Significant amount of nitrogen may be lost in gaseous form by the denitrification process in soil. Harvesting of agricultural crops, or transportation of logs from forests, represent nutrient loss from these ecosystems.

In an undisturbed ecosystem, (i.e., an ecosystem in which human activities are absent or nearly so) the input of nutrients may approximately equal the output of nutrients, rendering the nutrient cycles more or less balanced. Generally, the absolute amounts of nutrient moving in (input) and moving out (output) of the ecosystem are much less than the amount of nutrients cycled within (amongst different components) the ecosystem. Severe disturbances in the ecosystem (e.g., tree felling, insect outbreak, fire, soil erosion, etc.) may make the nutrient cycles unbalanced and the ecosystem unstable. The soil can be lost rapidly by erosion after removal of natural vegetation.

Internal Nutrient Cycling

Plants absorb varying amounts of nutrients from the soil. Due to decomposition of dead organic matter, nutrients are continuously regenerated and stored in soil in forms available to the plant. A dynamic state exists in soil, with nutrient regeneration and absorption occurring simultaneously. The transfer of nutrients from the soil to plants by the process of nutrient absorption is known as **uptake**. The absorbed nutrients are metabolically incorporated in plants during growth. Periodically, nutrients are recycled, i.e., brought back to soil through **litter fall** from vegetation, animal remains and faecal matter, etc. The aboveground, as well as root detritus decompose to regenerate the nutrients. Eventually, nutrients contained in the detritus on soil surface and within, are regenerated by decomposition in plant-available forms.

When the uptake of nutrients exceeds the amount recycled (e.g., as in the case of a young growing forest), a fraction of the uptake is retained in the standing crop. This **retention** of balance nutrients in the standing crop leads to increase in nutrient content of the ecosystem. Thus, in a nutrient cycle :

Retention = Uptake – Recycle.

Rates of nutrient uptake, recycle and retention vary widely in different ecosystems. A large number of chemical methods are available for determining the amounts of different nutrients per unit weight of biomass or soil. By determining changes in the nutrient concentrations and biomass with time, the nutrient budget of the ecosystems can be computed.

18.9 Nitrogen Cycle

The ultimate source of nitrogen to the ecosystem is molecular nitrogen in the atmosphere, which cannot be directly metabolised by plants or animals. Native rocks do not contain nitrogen, so do not contribute nitrogen to plants or animals. Thus, all the nitrogen accumulated in biomass, detritus and humus in various ecosystems, is derived from the atmosphere by biological activities. Molecular nitrogen enters the biological pathways of nitrogen cycle due to the activities of several free living and symbiotic nitrogen fixing microbes (Fig. 18.6). Nitrogen fixation in terrestrial ecosystems is predominantly carried out by symbiotic microbes, whereas bulk of fixation in aquatic ecosystems is done by free-living microbes.

As you know, important **free-living** nitrogen fixing bacteria residing in soil are : *Azotobacter* (aerobic) and *Clostridium* (anaerobic). A variety of cyanobacteria are mainly responsible for nitrogen fixation in flooded rice fields in the tropics. *Anabaena*, *Aulosira* and *Nostoc* rank amongst the important nitrogen-fixing cyanobacteria. Legumes represent most effective symbiotic combination with the bacteria *Rhizobium*, living in their root nodules. Legumes play an important role in the nitrogen economy of natural terrestrial, as well as man-made agricultural, ecosystems. Several higher plant species other than legumes (e.g., *Casuarina* and *Alnus*), also produce nodules harbouring *Frankia*, a nitrogen-fixing actinomycete. Another bacterium, *Azospirillum*, growing on the root surface of several tropical grasses, also fixes nitrogen; this combination where the nitrogen-fixing microbe does not penetrate

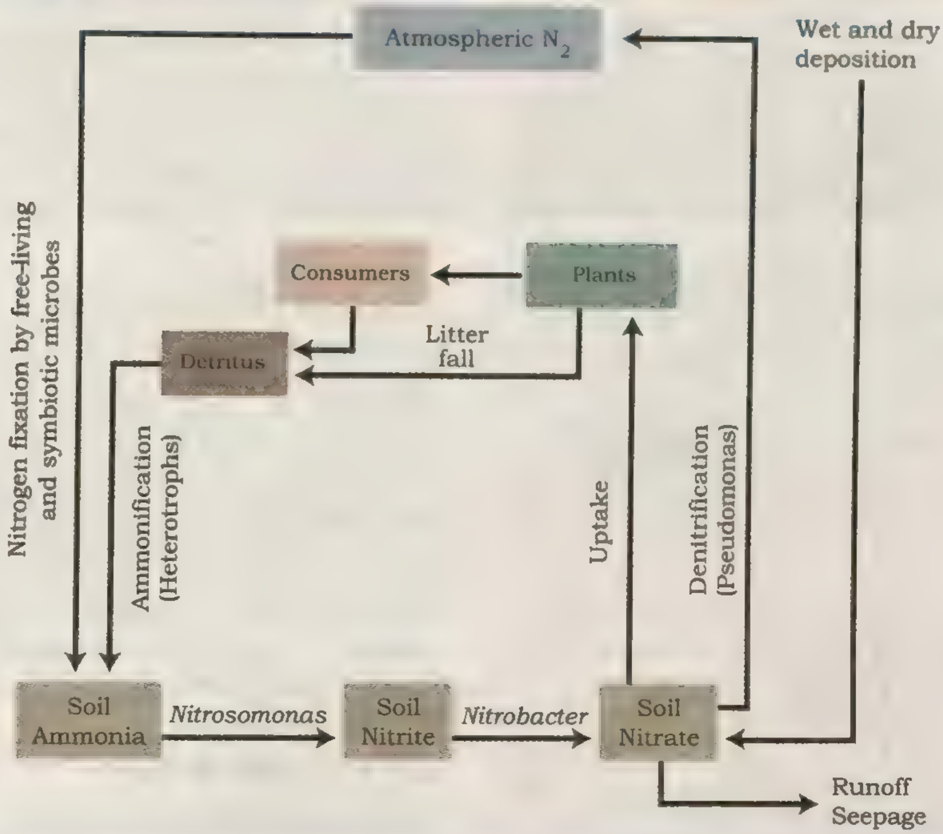


Fig. 18.6 *A generalised nitrogen cycling model of a terrestrial ecosystem*

deep into host tissues, is known as **associative symbiosis**.

Formation of ammonia from organic nitrogenous compounds, and its oxidation to nitrate by a succession of microbes, represents key transformations of nitrogen in soil. **Ammonification** is done by many heterotrophic bacteria, actinomycetes and fungi, by enzymatically degrading organic nitrogen, like protein and nucleic acid contained in detritus, into ammonia. After meeting their own metabolic requirements, these microbes release the excess ammonia in the soil. Next, ammonia is converted into nitrate by a group of chemo-autotrophic bacteria through a two-step process called **nitrification**. Initially, ammonia is converted to nitrite by the bacterium *Nitrosomonas*, followed by the conversion of nitrite into nitrate by *Nitrobacter*. If the soil is waterlogged and anaerobic, another group of microbes, the denitrifiers, become active. *Pseudomonas*, the most common denitrifying bacterium, thrives best under poorly-aerated and detritus-rich conditions. Denitrifying bacteria transform nitrate nitrogen to nitrous and nitric oxides, and ultimately to gaseous nitrogen.

Most higher plants are able to absorb nitrate from the soil. Through the metabolic assimilatory nitrogen reduction occurring in plant cells, the absorbed nitrate is ultimately converted to organic nitrogen. A fraction of nitrogen incorporated in plant tissues may be utilised by the consumers, and ultimately all dead remains find way to decomposers through detritus. Thus, the involvement of

various organisms in ecosystem nitrogen cycle is extensive and highly complex.

18.10 Phosphorus Cycle

The requirement for phosphorus is critical because it is a major constituent of nucleic acid, cell membrane, cellular energy transfer systems, bones and teeth. Rocks and natural phosphate deposits are the main reservoirs of phosphorus. Unlike the nitrogen cycle, the phosphorus cycle (Fig. 18.7) involves fewer steps and fewer kinds of microbes. Nitrogen and phosphorus cycles differ radically on two accounts. Firstly, atmospheric inputs of phosphorus through rainfall are much smaller than nitrogen inputs, and gaseous exchanges of phosphorus between organisms and environment are negligible. In contrast, main input of phosphorus in terrestrial ecosystems comes from the weathering of phosphorus-containing minerals in the soil. Secondly, phosphorus shows high sorption or fixation capacity in strongly acidic, as well as alkaline soils, as a result of which phosphorus availability to plants is drastically reduced. Phosphorus occurs in soil solution mainly as orthophosphate (PO_4^{3-}). Plants absorb phosphate from soil and incorporate it into organic compounds. Phosphatising bacteria maintain supply of phosphate ions by converting organic phosphorus contained in detritus. Absorption of phosphorus by the higher plants is promoted by the presence of mycorrhizae.

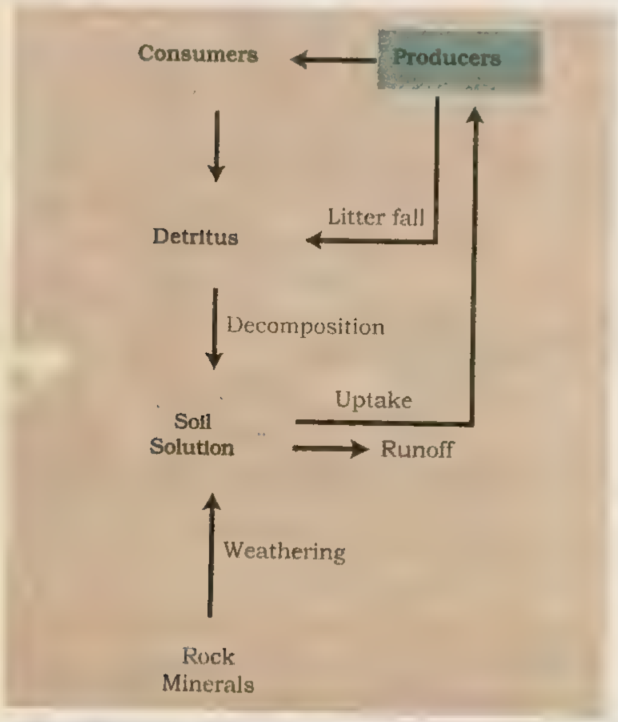


Fig. 18.7 A generalised phosphorus cycling model of a terrestrial ecosystem

18.11 Major Biomes

The regional biotic units, the biomes, are easily recognised by the life form of the climax vegetation. But the biome includes besides the climax community, all associated developing and modified communities occurring within the same climatic region. For instance, a forest biome may include young successional forests and open grass-dominated tracts located within the large expanse of mature forest. Ecological characteristics of forest, grassland/savanna, and desert biomes are described below.

Table 18. 2 : Typical Climatic Conditions in Major Forest Types in India

Forest type	Mean annual temperature (°C)	Mean annual rainfall (mm)	Dry months during the year*
Tropical rain forest	23-27	2000-3500	2-3
Tropical deciduous forest	22-32	900-1600	6-8
Temperate broad-leaf forest	6-20	1000-2500	3-5
Temperate needle-leaf forest	6-15	500-1700	3-5

* Month in which rainfall is <50 mm.

Forest Biomes

The characteristic vegetation of forest biomes is dominated by densely growing trees having a closed, or nearly so, canopy cover. Depending upon the climate type, a wide variety of forest types occur in the world. Forests found in colder temperate regions differ from the forests in tropical regions in terms of structure, productivity and nutrient cycling. In the northern hemisphere, as one proceeds from the equator northward to arctic region, consecutive belts of tropical, temperate deciduous and temperate coniferous forest biomes are observed. Tropical rain forest biome occurs in warm and high rainfall regions (near equator) of the world with plenty of soil water availability throughout the year. On the other hand, tropical deciduous forest biome extends to the outer tropics, having lesser seasonal rainfall and prolonged soil drought during the year. The temperate forest biomes distributed in mid-latitudes (40-60° N lat.) include two contrasting types, dominated by either broad-leaf deciduous species, or by needle-leaf evergreen species. Temperate broad-leaf forest biome experiences relatively mild cool environment, but the climate in temperate needle-leaf coniferous forest biome is cold, with the ground being covered with snow for 5-6 months.

Major forest biomes in India are :

(i) Tropical rain forest biome;
(ii) Tropical deciduous forest biome;
(iii) Temperate broad-leaf forest biome; and
(iv) Temperate needle-leaf or coniferous forest biome.

Tropical Rain Forests

In India, tropical rain forests are discontinuously distributed mainly along Western Ghats and in North-eastern Himalayas. *Dipterocarpus* and *Hopea* are the most common tree species in Indian rain forests. Figure 18.8 shows a typical tropical rain forest in Western Ghats. These evergreen tropical rain forests, possessing highest standing crop biomass among all biomes, show

Fig. 18.8 *A view of tropical rain forest in Western Ghats* (Courtesy : Dr. S.N. Rai)

30-40 m tall canopy structure with 4-5 strata formed by different plant species. Some of the dominant trees have umbrella-like canopy extending above the general canopy of the forest. Many tree species show buttresses (swollen stem bases), large leaves with drip tips and round the year leaf fall. Woody climbers and epiphytes grow profusely in these forests. The soil of rain forest is highly leached and has low base content. Large amounts of nutrients in rain forests are stored in the tall vegetation, whereas the nutrient storage in soil is low.

Tropical Deciduous Forests

The tropical deciduous forests occur widely in the northern and southern parts of our country in plain and low hilly areas. Towards the north-west, the deciduous forests grade into thorn forests. A view of tropical deciduous forest is shown in Figure 18.9. Sal (*Shorea robusta*) and teak (*Tectona grandis*) are the dominant tree species in deciduous forests. Other useful species are tendu (*Diospyros melanoxylon*), chiraunji (*Buchanania lanzan*), khair (*Acacia catechu*). These forests are of short stature (10-20 m height) and show contrasting seasonal aspects. During rainy season, the forest is lush green with dense foliage and thick herbaceous layer. But the leaves of most tree species drop before the advent of summer,

Fig. 18.9 *A view of tropical deciduous forest on the Vindhyan plateau* (Courtesy : Dr. K.P. Singh)

turning the forest largely leafless along with dried up herbaceous layer. Many tree species possess thick barks, giving protection from frequent fires. The deciduous forest soil is richer in nutrients due to lesser leaching.

Temperate Broad-leaf Forests

Temperate broad-leaf forests mainly occur between 1500 and 2400 m altitude in the western Himalaya (Fig. 18.10). Several species

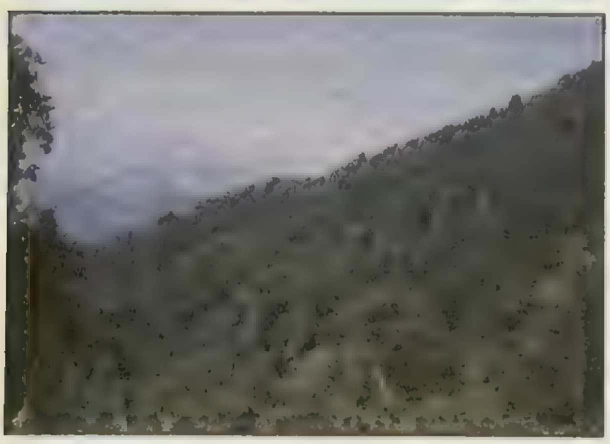


Fig. 18.10 *A tilonaj oak (Quercus floribunda) forest (in the background) in western Himalaya* (Courtesy : Dr. S.P. Singh)

of oak (*Quercus*) predominate in the temperate broad-leaf forests. These include banj oak (*Quercus leucotrichophora*), khrsn oak (*Q. semecarpifolia*), tilonaj oak (*Q. floribunda*) and rianj oak (*Q. lanuginose*). All oak species in the Himalayan region are evergreen. The evergreen oaks in Himalaya show peak leaf fall during summer, but never become leafless. These four strata forests have 25-30 m height. The tree canopy is dense, herbaceous layer is least developed, and grasses are generally lacking. The oak forests are often rich in epiphytic flora.

Temperate Needle-leaf or Coniferous Forests

In the Himalaya, the temperate needle-leaf

Fig. 18.11 *Cypress (Cupressus torulosa) forest in western Himalaya* (Courtesy : Dr. S.P. Singh)

coniferous forests are distributed over 1700 to 3000 m altitude. The temperate needle-leaf or coniferous forests contain economically valuable gymnospermous trees, like the pine (*Pinus wallichiana*), deodar (*Cedrus deodara*), cypress (*Cupressus torulosa*), spruce (*Picea smithiana*) and silver fir (*Abies pindrow*). Coniferous forests are taller (30-35 m) and possess evergreen canopy of long needle-like leaves. In different species, needle leaves may persist on the canopy for 2-7 years, therefore the canopy always remains green. In many species, the canopy is cone-shaped (Fig. 18.11).

Grassland and Savanna Biomes

Grassland

Grassland ecosystems have treeless herbaceous plant cover, dominated by a wide variety of grass species (family, *Poaceae*). Associated with grasses are several herbaceous dicotyledonous species, especially legumes, which play important role in nitrogen economy. Amongst the best known grassland biomes are the extensive "prairie" in the north America and "Steppe" in Russia. The rainfall in grassland region is considered too low to support a forest and much higher than the rainfall in deserts.

Grazing by large herbivores and fire play significant role in maintaining the dominance of grasses and eliminating the invasion of woody species. Morphologically, grasses are either sod-formers, which develop a solid mat of grass cover, or bunch grasses, which grow in separate bunches. The height of grassland vegetation is highly variable, ranging from as low as few centrimeters in arid regions to more than one and half meters in moist regions. Corresponding to above height range, the shoot biomass may vary widely from about 50 to 1000 g m^{-2}. Most remarkable aspect of grassland structure is its extensive root system, highly ramifying through the soil horizons. The primary productivity in grassland is directly related to the amount of rainfall.

Savanna

Commonly the term **savanna** implies a well developed grass cover, interspersed with scattered shrubs or small trees. A savanna is shown in Figure 18.12. The height of woody species may vary from 1-8 meters. Savannas are widely distributed in warm parts of central and southern Africa, India, northern and east-central South Africa and northern Australia. Although some savannas may be natural, many others are anthropogenic. In India, all savannas are believed to be derived by the degradation of original tropical forests, and maintained in their current state by continued grazing and fire for centuries.

Most abundant grasses in Indian savannas are *Dichanthium, Sehima, Phragmites, Saccharum, Cenchrus, Imperata* and *Lasiurus*. Generally, the woody species in a savanna are the residual species from the original forest from which the savanna has been derived. Some common trees and shrubs in savannas are *Prosopis, Zizyphus, Capparis, Acacia, Butea*, etc.

Fig. 18.12 *A typical savanna on the Vindhyan plateau (Courtesy : Dr. K.P. Singh)*

Savannas occur in tropical areas with highly seasonal climate, having distinct wet and dry periods. Availability of soil moisture determines the species composition and productivity of savannas. The effect of soil moisture variation may be modified by fire, soil nutrients and herbivores. An important aspect of tropical savannas is the abundance of grass species possessing C_4 photosynthetic capability. As you know, these species are able to sustain high level of primary productivity even with low soil moisture availability. Although the root system of grasses is well developed in the upper 30 cm soil horizons, the woody species usually send their roots to deeper horizons.

Desert Biome

Desert biome experiences prolonged moisture scarcity. Deserts have been variously classified as true deserts, having less than 120 mm annual rainfall, or **extreme desert** showing less than 70 mm yr^{-1} rainfall. On the basis of temperature, deserts are distinguished into **hot**

Fig. 18.13 *A view of a typical desert biome*
(Courtesy : Dr. K.P. Singh)

deserts and **cold deserts**. Nevertheless, in desert biomes, evaporation from soil always exceeds rainfall by 7 to 50 times. Most of the deserts are distributed around the Tropic of Cancer and Tropic of Capricorn, between 15° and 35° latitudes, in both northern and southern hemispheres. Warm or hot days and cool nights are the characteristics of most deserts. The biomass and primary productivity levels in deserts are low. A typical desert landscape is shown in Figure 18.13.

The desert vegetation is dominated by three life forms : (i) ephemeral annual herbs, which grow only when sufficient moisture is available, (ii) typical succulent xerophytes like cacti, which store water, and (iii) shrubs and small trees like *Prosopis*, *Salvadora* and *Tamarix*, whose deep tap roots may reach the water table. *Cenchrus* is an abundant grass in the desert regions. In some deserts tall succulents, mostly cacti, become highly noticeable projecting above the general canopy.

SUMMARY

Ecosystem is comprised of two basic components : abiotic (inorganic materials, air, soil, water, etc.) and biotic (producer, consumer and decomposer organisms). Biotic and abiotic components are physically organised to provide a characteristic structure (e.g., species composition, stratification) of the ecosystem. Ecosystem structure can also be depicted through food relationship of producers and consumers known as the trophic structure.

Productivity and decomposition are two important functions in ecosystem. The former is involved in food production and the latter leads to the breakdown of organic matter. Primary productivity is the rate of capture of solar energy or biomass production by producers. The rate of total production of organic material or capture of energy is known as gross primary productivity. Net primary productivity represents the balance after meeting the cost of respiration. Secondary productivity is the rate at which food energy is assimilated at the trophic levels of consumers. Decomposition involves breakdown of complex organic compounds in detritus to carbon dioxide, water and inorganic nutrients by decomposers. Three main processes of decomposition (e.g., fragmentation of detritus, leaching and catabolism) operate simultaneously on the detritus.

Energy flow and nutrient cycling are important functions in the ecosystem. Energy flow is unidirectional. It involves : (i) the conversion of light energy into food, and (ii) transfer of energy from one organism to another. The trophic levels are connected by the transfer of food or energy along the food chain. Ecological efficiencies indicate the efficiency with which organisms exploit

their food and convert the food into biomass made available to the next higher trophic level.

Nutrient cycles involve storage and transfer of nutrients through various components of the ecosystem so that the nutrients are repeatedly used. Nutrient cycling is of two types, gaseous and sedimentary. While the reservoir of gaseous type of nutrient cycle is generally located in the atmosphere or the hydrosphere, the reservoir of sedimentary type exists in the earth's crust. Ecosystem nutrient cycles have three aspects : input, output and internal cycling of nutrients. Nitrogen and phosphorus cycles are well known examples of gaseous and sedimentary types, respectively.

The biomes are easily recognised by the life forms of the climax vegetation. Forest, grassland/savanna and desert biomes occupy most of the land area under natural vegetation. Forest biomes are dominated by trees, generally having a closed canopy. While grasslands are dominated by herbaceous species, savanna is characterised by herbaceous vegetation interspersed with trees. Deserts have low herb or shrub cover with considerable bare ground.

EXERCISES

1. Fill in the blanks :
   (a) The pyramid of ____________ is always upright.
   (b) Inverted pyramid is generally found in ____________ .
   (c) In oceans, the productivity is generally limited by ____________ .
   (d) Humus serves as a reservoir of ____________ .
   (e) Dead plant parts and animal remains are called ____________ .
2. Which of the following is an abiotic component of the ecosystem?
   (a) Bacteria
   (b) Humus
   (c) Plants
   (d) Fungi
3. Which of the following processes helps in nutrient conservation?
   (a) Mineralisation
   (b) Immobilisation
   (c) Leaching
   (d) Nitrification
4. Which of the following represents the sedimentary type of nutrient cycle?
   (a) Nitrogen
   (b) Carbon
   (c) Phosphorus
   (d) Oxygen
5. Which of the following is a free living nitrogen fixing bacterium present in soil?
   (a) *Azotobacter*
   (b) *Nitrosomonas*
   (c) *Rhizobium*
   (d) *Pseudomonas*

6. What fraction of assimilated energy is used in respiration by the herbivore?
   (a) 20 per cent
   (b) 30 per cent
   (c) 40 per cent
   (d) 60 per cent
7. Match the items in column I with column II :

	Column I		Column II
(i)	Tropical rain forest	(a)	*Shorea robusta*
(ii)	Tropical deciduous forest	(b)	*Quercus*
(iii)	Temperate broad-leaf forest	(c)	*Cedrus deodara*
(iv)	Temperate needle-leaf forest	(d)	*Dipterocarpus*
		(e)	*Abies pindrow*

8. Distinguish between the following :
   (a) Grazing food chain and detritus food chain.
   (b) Gaseous and sedimentary types of nutrient cycling.
   (c) Wet deposition and dry deposition.
9. Distinguish between the following :
   (a) Abiotic and biotic component.
   (b) Net primary productivity and gross primary productivity.
   (c) Food chain and food web.
10. What is primary productivity? Give the range of primary productivity in different ecosystems of the world?
11. What is Ecological efficiency? Explain its significance?
12. Give an account of factors affecting the rate of decomposition.
13. Briefly describe the tropical forest biomes.
14. Give an account of energy flow in an ecosystem.
15. Briefly describe the processes and products of decomposition.
16. Outline the salient features of the nitrogen cycle.
17. What is a grassland? How does it differ from savanna?
18. Give the major characteristics of the desert.

Chapter 19

Natural Resources and their Conservation

By now, you know that the earth's biosphere is endowed with extremely diverse kinds of environments which provide countless goods and services to human kind. Any component of the natural environment that can be utilised by man to promote his welfare is considered as a **natural resource**. The natural resource can be a substance, an energy unit, or a natural process or phenomenon. Land, soil, water, forests, grasslands, etc. are examples of important natural resources. Some of the resources (e.g., soil, water) are important components of the life-supporting system. Besides being source of food, fodder and shelter, natural resources also provide recreational opportunities, solace and even inspiration to mankind. Natural resources have been exploited by humans since the beginning of civilisation, or even before. However, since the resources were abundant in relation to human population, no significant depletion occurred. During the last millennia, human population has increased considerably, causing serious damage or destruction of natural resources. In this chapter, we will study major kinds of natural resources, causes of their degradation and their conservation.

19.1 Classification of Natural Resources

Natural resources vary greatly in their location, quantity and quality. For instance, a particular forest type may occur only in certain countries. Also, the geographical area covered by forest and wood quality may differ widely in different countries. Some resources can be reused after being used once. A convenient classification of resources is based upon their exhaustibility and renewability (Fig. 19.1). Basically, resources can be categorised as **Inexhaustible** and **Exhaustible**.

Inexhaustible Resources

Inexhaustible resources are available in unlimited quantities on the earth. While some inexhaustible resources remain virtually unaffected by human impact, many others may show some changes in their quality, though their quantity may remain unchanged. Resources like solar energy, wind power, tide power, rainfall, and even atomic energy, cannot be exhausted significantly at global level due to human activities. Such resources may sometimes be locally affected by human activities; for example, pollution may change the quality of air.

Exhaustible Resources

A large number of natural resources are exhaustible, i.e., they have finite supply on the earth and can be exhausted if used indiscriminately. Broadly, the exhaustible resources can be either **renewable** or **non-renewable**.

Renewable resources : Most of the biotic resources are renewable. The growth and reproduction of such resources can be successfully managed so that these resources are continuously regenerated. However, if the consumption of these resources continues to exceed their rate of renewal, not only their

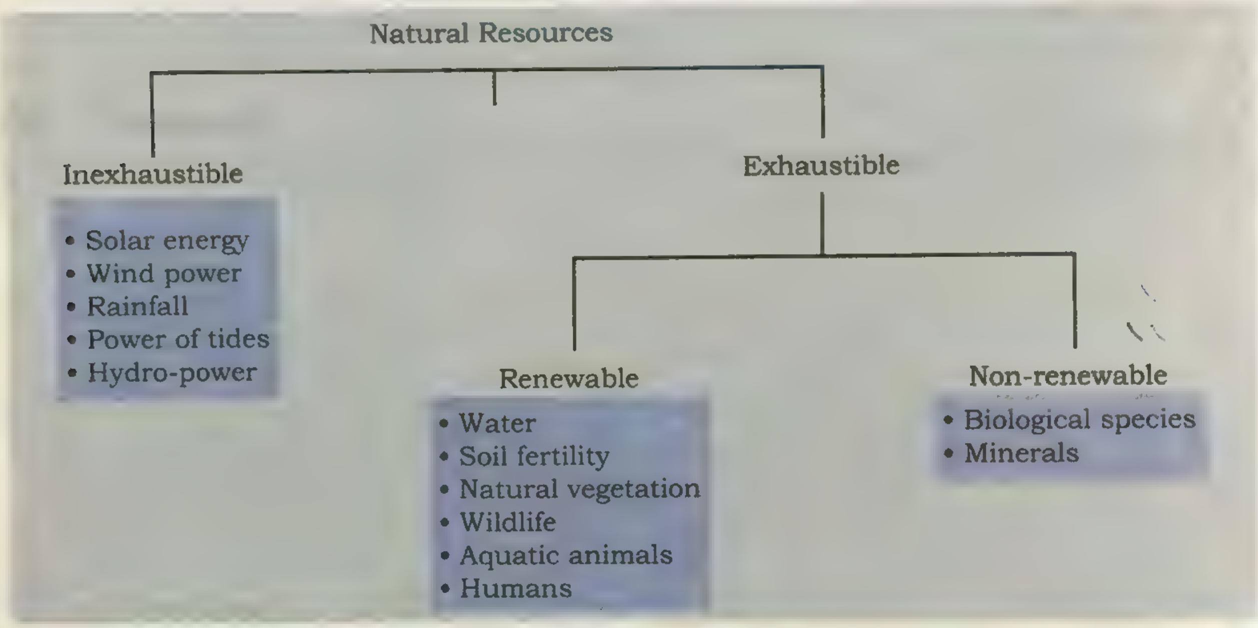


Fig. 19.1 *Basic types of natural resources. Also shown are few examples of different kinds of resources*

quality becomes affected, they may even get totally exhausted.

Selected examples of ecosystems and their important renewable products are :

(i) Forests, which yield timber and other plant products
(ii) Rangelands, which sustain grazing animals for milk, meat and wool production
(iii) Wildlife, which maintains food chain
(iv) Agricultural systems, which yield food and fibre, and
(v) Marine and freshwater systems, which yield various foods from plants and animals.

Soil and water are other renewable resources.

Non-renewable resources : Some biotic resources are non-renewable, i.e., they cannot be regained or reconstructed once they are used up. Biological species, which have evolved in nature during the course of millions of years, are considered non-renewable. Once a biological species becomes extinct from the earth, it cannot be recreated by man. Many abiotic resources are also non-renewable. For instance, fossil fuels (coal, petroleum and gas) and metals once extracted, cannot be regenerated at the place of extraction. After unlimited extraction and use, the fossil fuels will certainly get exhausted.

Amongst the earth's resources, the following contribute significantly to human welfare :
(i) Soil, (ii) Water, (iii) Land, (iv) Energy, (v) Marine, and (vi) Mineral.

19.2 Soil Resource

The yield of all biotic products in terrestrial ecosystems depends on soil fertility. You know from Chapter 16 that soil is composed of inorganic particles, organic matter, air, water and a variety of organisms. It takes decades, or even centuries for the development of soil horizons having different physico-chemical properties. Human activities often create

worldwide problems, like soil erosion and depletion of fertility.

Soil Erosion

Movement of water and air removes top soil from the land by the process of **erosion.** Abundant plant cover significantly reduces soil erosion. Human activities accelerate soil erosion by removing natural plant cover. From croplands in India, millions of tons of top soil are eroded into sea each year. Erosion causes a significant loss of soil fertility by transporting organic matter and nutrients that are essential part of the soil. The eroded soil, which gets into streams, rivers and lakes in the form of sediments, affects water quality and the habitats of aquatic organisms.

Depletion of Soil Fertility

When natural vegetation is removed to develop agricultural systems, as has happened in most parts of India, and indeed, in the world, not only the nutrients stored in vegetation are removed, the organic matter and nutrients accumulated in the soil are also lost. From agricultural systems, nutrients are exported through crop harvest. Thus, over a period of time the agricultural soil inevitably loses its fertility.

Soil Conservation

Several soil and crop management practices can minimise erosion and reduce nutrient depletion of agricultural soils. These include practices like conservation tillage, organic farming, crop rotation (especially cereal with legumes), contour ploughing and strip-cropping terraces, etc. In contrast to conventional tillage, conservational tillage incorporates residues from previous crops into the soil, thereby increasing the organic matter, which in turn improves soil moisture and nutrients. Reduced tillage and no-tillage are two kinds of conservation tillage.

Efforts to improve erosion-affected soils involve two steps :

(i) stabilising the soil to prevent further erosion, and
(ii) restoring the soil fertility.

Soil stabilisation will need seeding of bare ground with plants that can survive harsh conditions, e.g., drought-resistant grasses. Such plants eventually establish vegetation cover on the soil, preventing further erosion. With increasing addition of detritus, the soil organic matter, nutrient and moisture levels improve. The restoration of soil fertility to its original level is a slow process. Application of biofertilizers is useful in enhancing soil fertility. Various organic farming measures, which provide increased organic input to soil, have long-term beneficial effects on soil fertility.

19.3 Water Resource

About three-fourth of the earth's surface is occupied by oceans, which contain about 97.5 per cent of the earth's water in strongly saline condition. The rest 2.5 per cent is fresh water, and all of this is not available for direct human use. Most of the fresh water is frozen as polar or glacial ice (1.97 per cent). Remaining fresh water occurs as groundwater (0.5 per cent) and water in lakes and rivers (0.02 per cent), soil (0.01 per cent) and atmosphere (0.001 per cent). Thus, only a small fraction of fresh water is available for human consumption. More so, the distribution of fresh water is geographically uneven, varying greatly from country to country and even within a country from one region to another.

About 84 per cent of the total global evaporation occurs from ocean surface and 16 per cent from land surface. At any given time, the amount of moisture in the air is only enough to meet a total rainfall requirement of 10 days. Thus, there is very fast movement of water from ocean and land into the atmosphere, and an average residence time of water in the air is only about 10 days. About 77 per cent of the total rainfall on earth is received on the sea surface (as against 84 per cent evaporation from this segment) and 23 per cent on land (16 per cent share of total evaporation to the atmosphere). There is a net gain of 7 per cent rainfall water on land, and this excess is returned to the oceans by surface runoff through rivers and sub-surface water flows. On global basis, the hydrological cycle is perfectly balanced as the total annual evaporation matches with annual precipitation.

Water Use

On global basis, the water use has increased 4-8 per cent per year since 1950, and the

consumption rate varies among countries. Worldwide, approximately 70 per cent of total water use is accounted by agriculture, only about 1.1 per cent is used for domestic and municipal supplies, and the rest is consumed by various industries, such as cement, mining, pharmaceutical, detergent and leather industry, etc.

Problems Related with Water Resources

About 40 per cent of the world's population lives in arid or semi-arid regions. These people spend substantial amounts of time, energy and effort in obtaining water for their domestic and agricultural uses. To meet the needs of the huge population, surface waters (ponds, lakes, rivers, etc.) are overdrawn. Due to over-use of surface water, the nearby wetlands may dry up. When more groundwater is removed for human use than can be recharged by rainfall or snow-melt, the groundwater may also dry out.

Excessive irrigation in semi-arid and arid regions can cause salt accumulation in the soil, due to which crop productivity may decline. The continuous depletion of groundwater along the coastal regions often leads to the movement of saline sea water into freshwater wells, spoiling their water quality. Estuaries become more saline and consequently less productive when surface waters are overdrawn.

Heavy rainfall results in rapid runoff from areas having exposed soil, particularly on mountain slopes. This not only causes soil erosion, but puts lowland areas at extreme risk of destruction due to flooding. Uncontrolled soil erosion results in sedimentation of waterways that can harm fisheries.

Conservation and Management of Water

Main approaches for conservation of water are :

(i) Reducing agricultural water wastage by increasing efficiency of irrigation. By the traditional method of irrigation, plants absorb less than 50 per cent of the water applied to the soil, the rest is lost.

(ii) Reducing water wastage in industry by recycling the used water.

(iii) Reducing domestic water wastage by constructing waste water treatment plants and recycling the treated water.

(iv) Rainwater harvesting by employing practices to store rainwater and recharge groundwater.

(v) Afforestation and protection of watersheds to improve water economy.

Some important water management approaches to provide a sustainable supply of high quality water are :

(i) Construction of dams and reservoirs to ensure year-round supply of water and, controlling floods.

(ii) Desalinisation of seawater and saline groundwater, making it fit for drinking and other purposes. Diversion of water bodies (e.g., through canal) to increase the natural supply of water to a particular area.

(iii) Regular dredging and desiltation of water bodies.

19.4 Land Resources

Earth's one-fourth area is formed by land, which is largely covered with natural forests, grasslands, wetlands, and man-made urban and rural settlements along with agriculture. Low-lying areas covered with shallow water are called **wetlands**. The wetlands are transitional zones between terrestrial and aquatic areas.

19.5 Forests

Approximately one-third of the earth's total land area is covered by forests. The forests are storehouse of biodiversity and provide important environmental services to mankind. These services originate from the following key functions of forests.

(i) Productive functions, include production of wood, fruits and a wide variety of compounds, such as resins, alkaloids, essential oils, latex, etc.

(ii) Protective functions, include conservation of soil and water; prevention of drought, shelter against wind, neat, radiation and noise.

(iii) Regulative functions, involve absorption, storage and release of gases (CO_2, O_2), water,

Table 19.1 : Forest Cover in India (1999 Estimate)

Class	Area (sq. km.)	% Geographic area
Dense forest[1]	3,77,358	11.5
Open forest[2]	2,55,064	7.8
Mangrove[3]	4,871	0.1
Sub-total	6,37,293	19.4
Scrub[3]	5,896	1.6
Non-forest (other land use)	25,98,074	79.0
Total	32,41,263	100.0

[1]Canopy cover >40 per cent of land
[2]Canopy cover 10-40 per cent of land
[3]Canopy <10 per cent of land.

mineral elements and radiant energy. Such regulative functions improve atmospheric and temperature conditions, and enhance the economic and environmental value of the landscape. Forests effectively regulate floods and drought, and the global biogeochemical cycles, particularly of carbon.

Forest Area in India

At the beginning of the twentieth century, about 30 per cent of land in India was covered with forests. But by the end of the twentieth century, the forest cover was reduced to 19.4 per cent (Table 19.1). This is considerably less than the optimum 33 per cent forest area recommended by the National Forest Policy (1988) for the plains, and at least 67 per cent for the hills. Of the existing forests, less than two-third are dense forests, and the rest are open degraded forests. Today, per capita forest area available in India is 0.06 ha, which is much below the average for the world (0.64 ha per person).

Deforestation

World's forest cover has been shrinking rapidly, especially in the developing countries located in tropics. While the temperate forests have lost only 1 per cent or less of its area, the tropics have lost more than 40 per cent of the forest cover due to deforestation. The main causes of deforestation are expansion of agriculture, urbanisation, industrialisation, excessive commercial use of timber, fuel wood, other forest products and cattle grazing. The current deforestation rate in tropics is estimated to be more than 10 million ha per year. If this rate of deforestation continues, it is feared that remaining tropical forests may disappear within a century.

Forests, particularly on mountains, provide considerable protection from floods by trapping and absorbing precipitation, and slowly releasing it later. When the forest is removed, the amount of runoff water flowing into rivers and streams increases several fold. Deforestation results in increased soil erosion and decreased soil fertility. In drier areas, deforestation can lead to the formation of deserts.

Deforestation causes the extinction of plant, animal and microbial species. It also threatens indigenous people, whose culture and physical survival depends upon the forests. Deforestation also induces regional and global climate change. Generally, rainfall declines in deforested areas and droughts become common. Deforestation contributes to global warming by releasing stored carbon into the atmosphere as carbon dioxide, which is a greenhouse gas (see Chapter 21).

Forest Conservation and Management

Forest conservation and management programmes should ensure : (i) sustainable supply of tree products and services to people and industry, and (ii) maintenance of long-term ecological balance through protection, restoration and conservation of forest cover. Extensive planting of trees through **afforestation** programmes is needed to save

the diminishing forest cover. To achieve these goals the following forestry practices should be carefully integrated : (i) protection or conservation forestry, and (ii) production or commercial forestry.

Protection or **conservation** forestry involves protection of degraded forests to allow recoupment of their flora and fauna. Well-stocked forests are managed scientifically for producing timber and other forest products without causing any negative environmental impact on the forest. Forest areas designated as national parks and sanctuaries are protected from human interference (for details see Chapter 20).

On the other hand, **production** or **commercial forestry** aims to fulfil the commercial demand, without causing denudation of natural forests, through intensive plantation in available land. Production plantations of fast growing trees (e.g., *Eucalyptus*) are raised using modern forestry techniques. Social forestry and agro-forestry programmes are also included in this category.

Social forestry aims to plant trees and shrubs on all unused and fallow land to provide fuelwood, fodder, etc., thereby reducing pressure on existing forests. For example, unused farmland, community land, road and rail sides, etc. are planted with suitable indigenous and/or exotic tree species.

Agro-forestry includes a variety of land uses, where woody species are grown in combination with herbaceous crops, either at the same time or in time sequence. For instance, **taungya system** involves growing agricultural crops between rows of planted trees (sal, teak). The well-known shifting cultivation or **jhum**, a traditional agro-forestry system widely practised in the north-eastern region of our country, involves felling and burning of forests, followed by cultivation of crops for few years, and abandoning cultivation to allow forest regrowth.

19.6 Grassland

Grasslands (also called **rangeland**) provide forage and habitat to domestic animals and wildlife. In rural areas, dried hay removed from grasslands, particularly from tall grasses, is also used as fuel or thatching material. Grass cover is extremely effective in binding soil particles with the help of highly branched fibrous root system, thereby significantly reducing soil erosion. In India, the area under various kinds of grass cover, including fallow and waste lands, is estimated to be about 18 per cent of the total land area. If we include the forested area (about 19 per cent of total land), most of which also supports grazing, about 37 per cent of land can be said to be available for grazing. The average annual production of dry grass or hay in India is about 250 million tons.

Degradation of Grassland

Degradation or destruction of grassland is mainly related to overpopulation. To enhance food production, grasslands possessing fertile soils are ploughed and converted to agricultural lands (e.g., North American prairies). In developing countries, grassland areas are frequently overgrazed. For example, the number of animals grazing in the arid and semi-arid regions of India has been found to be 2-10 times greater than the capacity of the grassland to feed the animals.

The lack of plant cover due to overgrazing causes soil erosion due to water and wind. When overgrazing occurs in combination with extended periods of drought, a once fertile grassland can be converted to a desert. The conversion of grassland (or forest) to desert is called **desertification**.

Grassland Management

Frequently employed measures of grassland management are :

(i) Protection from grazing to allow recovery of severely damaged vegetation.
(ii) Use of **rotational grazing**; while some areas are closed to grazing, allowing the plant cover to recover, grazing is permitted in other selected areas.
(iii) Removal of woody bushes or shrubs and weeds, which usually adversely affect the productivity of grasses.
(iv) Conservation of soil and water by reducing loss of soil and water from the grassland.
(v) Use of controlled burning to promote recycling of nutrients stored in dried mulch and to reduce woody species invasion.

19.7 Wetlands

Wetlands are low-lying areas, usually covered by shallow water, and have characteristic soils and water-tolerant vegetation. Wetlands may be either freshwater or salt water (coastal). Freshwater wetlands include **marshes** (where grass-like plants dominate), **swamps** (where trees or shrubs dominate), and periodically flooded **riverine** forests found in lowlands along streams.

Wetlands occupy almost 6 per cent of the world's land surface and provide crucial environmental services. Wetlands are often drained, dredged or filled up for housing and industrial purposes. They are increasingly threatened by agriculture, pollution, and engineering constructions such as dams.

Freshwater Wetlands

Wetland plants are highly productive and provide food and habitat to support a wide variety of organisms. Wetlands help control flooding by holding excess water, and the flood water stored in wetlands then drains slowly back into the rivers, providing a steady flow of water throughout the year. Wetlands also serve as groundwater recharging areas. Another important role of wetlands is to help clean and purify water runoff, even water that is polluted. Freshwater wetlands also provide important commercial products, including wild rice and various types of berries (e.g. black berries, blue berries, etc.). In addition, wetlands provide sites for fishing, boating, nature study, etc.

Saltwater Wetland

Coastal wetlands, also known as saltwater wetlands, include highly productive estuaries which provide food and habitat for a large number of marine organisms.

Mangrove swamps are coastal wetlands in tropics containing certain trees and shrubs growing best in the intertidal zone. Mangroves hold sediments and accumulate soil along the shoreline. As mangroves expand into the ocean, other plants colonise the soil left behind. Mangrove roots provide habitat for oysters, crabs and other marine organisms. Like freshwater wetlands, coastal wetlands are also being destroyed for space for coastal development and agricultural lands.

Wetland Conservation

Wetland conservation programmes are generally based on :

(i) Preparation of wetland inventories.
(ii) Identification of wetlands of critical importance for their protection.
(iii) Checking waste disposal in wetlands.
(iv) Reduction of excessive inflow of nutrients and silt into wetlands from surrounding uplands by keeping them under plant cover.

19.8 Energy Resources

Future energy needs of rapidly expanding human population will demand the exploitation of most energy sources. Broadly, energy resources can be recognised as non-renewable or renewable. **Non-renewable energy** resources include various fossil fuels and nuclear energy. Fossil fuels include petroleum products, natural gas and coal. Nuclear energy is mainly obtained from the nuclear fission of the uranium. The world reserves of fossil fuels and uranium are limited and will eventually be depleted. Burning fossil fuels for energy has negative environmental consequences, such as global warming, air pollution, acid rain and oil spills. It has become necessary to minimise use of non-renewable energy resources, and to replace them with renewable resources.

Renewable energy resources are regenerated by natural processes so that they can be used indefinitely. Renewable energy generally causes much less negative environmental impact than fossil fuels or nuclear energy. With the current state of technology, the generation of renewable energy is often more expensive than energy produced by fossil fuels or nuclear energy; however, with technological advances the costs of renewable energy is expected to decrease. Among the renewable energy sources, the most important one is solar energy. The other renewable energy resources are hydropower, wind, geothermal energy, ocean waves and tidal energy.

Solar Energy

Solar energy can be used directly or indirectly for human welfare. **Direct solar energy** is the

radiant energy, whereas **indirect solar energy** is energy obtained from materials that have previously incorporated the sun's radiant energy. Solar energy can be used for direct heating, and alternatively the heat converted into electricity (thermal electric generation). Photovoltaic cells convert direct solar energy into electricity. A back-up system is required to store and generate electricity when solar power is not operative at night or during cloudy days.

Among various energy resources where solar energy is utilised indirectly, **biomass energy** is the most important one. Biomass energy is obtained from those materials whose origin can be traced to photosynthesis, such as live plant material and dried residues, freshwater and marine algae, agricultural and forest residues (e.g., straw, husks, corn cobs, bark, sawdust, roots, animal wastes), etc. Biomass also includes biodegradable organic wastes from industries like sugar mills, breweries, etc. At least half of the world's population relies upon biomass as their main source of energy for domestic use. In India, fuel wood is still a major source of energy for domestic purposes in rural areas.

Biomass fuel, which can be a solid, liquid or gas, is burned to release its energy. Solid biomass includes wood, charcoal, animal dung and peat. Biomass can be converted to liquid fuels, especially methanol and ethanol, which can be used in internal combustion engines of automobiles. Gasoline mixed with 10-20 per cent ethanol can be used in conventional gasoline engines. Biomass, particularly animal waste, can also be converted into **biogas** in biogas digesters, by using the process of anaerobic microbial decomposition. Biogas is a clean anaerobic fuel whose combustion produces fewer pollutants than other combustible energy resources. It is composed of a mixture of gases (about 60 per cent methane and 40 per cent CO_2) and can be stored and transported easily.

Production of biomass for energy requires sufficient area of land and water. **Energy plantations** of plant species, showing high calorific value and growth rate, are raised in selected areas to produce biomass.

Other Renewable Energy Resources

Among other renewable energy resources, the following are important, but their availability differs in different regions.

Hydropower : Water falling from a height turns turbines to generate electricity. Hydropower produces approximately one-fourth of the world's electricity, and is usually cheaper than electricity produced by thermal power plants. However, building a dam to hold the water leads to several environmental problems; e.g., submergence of plant and animal habitats and displacement of people.

Wind energy : When fans are rotated by the action of wind, its energy can be used for generation of electricity. However, harvesting wind energy is possible only in the areas that receive fairly continual winds, such as islands, coastal areas, and mountain passes.

Geothermal energy : Heated groundwater flowing upward as hot water or steam, or as hot springs, can be used to turn turbines and generate electricity in geothermal power plants.

Tidal/Ocean waves energy : Tides and Ocean waves, produced by winds, have the potential to turn a turbine and generate electricity.

19.9 Marine Resources

About three-fourth of earth's surface is occupied by oceans. Marine resources can be broadly divided into two major categories, viz. living resources, which include the algae and the animals of the sea, and the non-living resources, which include various kinds of minerals.

Algal Resources

Marine algae vary greatly in form and range from one-celled microscopic flagellates to giant kelps, which attain a length of 100 to 150 metres. Green, blue, red and brown algae are common in oceans. Since ancient times, algae have been widely used as human food. In many countries, animals are still regularly fed on fresh or processed seaweed (e.g., *Laminaria* and *Fucus*). Marine algae have been used as a manure in many countries because of their high nutrient content. Balanced fertilizer can be made by mixing sheep manure, fish and shells with seaweeds.

Red algae (e.g., *Gracilaria* and *Gelidium*) are used for the extraction of commercially

important agar. Agar has wide applications in food and pharmaceutical indsutries. It is also used as a substrate for bacteriological and plant tissue culture studies.

Animal Resources

From the point of view of human use, fish, molluscs, crustaceans and mammals are important among the animals found in the ocean.

Fish : Marine fish provide considerable amount of food throughout the world. Besides, fish are used for the manufacture of many other edible products, like fish glue, fish meal, fish oil, fish protein and vitamins. Economically important fish can be grouped into two categories, namely **demersal fish** found at the sea-bottom, and **pelagic fish** floating free in the water column.

Molluscs : Important molluscs from commercial point of view are the mussel, oyster, clam, etc. Many types of molluscs are used as food. Besides, pearl oyster (bivalve) has considerable commercial importance.

Crustaceans : Some crustaceans like prawn, lobster and crabs are used as food. India ranks first among the prawn producing countries of the world.

Mammals : Whales, Dolphins and Porpoises are the economically important mammals found in the sea. Whales provide many valuable products, such as meat, skin frozen glands and liver oil. Fresh meat of all cetaceans has been used for human consumption.

Minerals in Sea

The sea is a storehouse of many valuable minerals. Most abundant elements in seawater are sodium, chlorine, magnesium and bromine, that are commercially extracted from sea-water. Mining of phosphorite nodules can meet the shortage of phosphate fertiliser.

19.10 Mineral Resources

The minerals occur naturally in the earth's crust, however, their distribution is not even. Minerals essential to our industrialised society and daily life are non-renewable resources. Due to the increase in industrialisation, the consumption of minerals has increased tremendously all over the world. The minerals now in short supply (e.g., silver, copper, mercury, tungsten, etc.) will probably be exhausted within next 20 to 100 years. Even the minerals which are relatively plentiful, e.g., iron and aluminium, will become extremely expensive because of the depletion of large, rich and easily accessible deposits of these metals. Minerals can be metallic, e.g., iron, copper, gold, etc. or non-metallic, e.g., sand, stone, salt, phosphates, etc. Some important minerals and their uses are given in Table 19.2.

Extraction (i.e., mining), processing and disposal of minerals have negative effects on environment. Mining not only disturbs and damages the land, but also pollutes the soil, water and air. The land that has been destroyed due to mining is known as derelict land or **mine spoil.** Such derelict lands can be reclaimed or restored to a semi-natural condition by re-vegetation to prevent further degradation, and also to make the land productive for other purposes.

Conservation of Minerals

Mineral conservation measures involve their recycling and reuse. In recycling, used and discarded items are collected, remelted and reprocessed into new products, e.g., iron scraps, aluminium cans, etc. Some minerals present in products can be recycled, e.g., gold, lead, nickel, steel, copper, aluminium, silver, zinc, etc.; however, minerals in other products are lost through normal use, such as paints containing lead, zinc or chromium. During reuse, used products are collected and used over and over again, e.g., reuse of glass bottles. The benefits of reuse are greater than those of recycling. All products, however, may not be reused. Recycling and reusing not only renew the mineral resources, but also help in : (i) saving unspoiled land from the disruption of mining, (ii) reducing the amount of solid waste that must be disposed, and (iii) reducing energy consumption and pollution.

The substitution of more abundant minerals for scarce minerals may prove useful,

Table 19.2 : Some Important Mineral Elements and their Uses

Mineral	Selected uses
Metal elements	
Aluminium	Structural material, packaging
Chromium	Chrome plate, steel alloys
Copper	Alloys material in gold jewellery, silverware, brass and bronze, electric wiring, pipes, cooking vessels
Gold	Jewellery, dentistry, alloys
Iron	Primary component of steel
Lead	Pipes, battery electrodes, pigments
Manganese	Alloy steels, disinfectants
Nickel	Coins, alloys, metal plating
Platinum	Jewellery, equipments, industrial catalyst
Potassium	Fertilizer, glass, photography
Silver	Jewellery, vessels, photography, alloy
Uranium	Nuclear bomb, electricity, tinting glass
Tin	Cans/containers, alloys
Zinc	Brass, electrodes, medicine
Non-metal elements	
Phosphorus	Medicine, fertilisers, detergent
Sulphur	Insecticide, rubber types, medicine
Liquid metal element	
Mercury	Thermometer, dental inlays, electric switches

provided environmental implications are kept in mind. In recent years, plastics, ceramics, high strength glass fibres and alloys have been substituted for scarcer materials like steel, tin and copper in many industries. Although substitution can extend our mineral supplies, it is not a solution of the problem. To maintain the extended supply of minerals for a longer time, consumers must decrease their mineral consumption by becoming a low waste society. Products that are durable and repairable should be encouraged to be used again instead of discarding them as waste. Manufacturing industries may also use the waste products of one manufacturing process as the raw materials for another industry.

19.11 Forests and Wildlife laws

Several legal provisions exist in our country to safeguard the national interests related to forests and wildlife. Notable amongst them are listed below.

Forest Act 1927 : This act aims to consolidate the law relating to forests, and its basic objectives are : (i) Setting up and managing reserved forests, protected forests and village forests; (ii) Protection of non-government forests and forest land; (iii) Control of movement of forest produce; and (iv) Control of cattle grazing.

Wildlife (Protection) Act 1972 (Amended 1991) : This act provides for protection of wild animals, birds and plants, and includes the following objectives : (i) Restriction and prohibition on hunting of animals; (ii) Protection of specified plants; (iii) Setting up and managing sanctuaries and national parks; (iv) Empowering zoo authority with control of zoos and captive breeding; and (v) Control of trade and commerce in wildlife, wildlife products and trophies.

National Forest Policy (1988) : The principal aim of our Forest Policy is to ensure environmental stability and maintenance of ecological balance, including atmospheric equilibrium, which are vital for all life forms, human, animal and plant. The derivation of direct economic benefit (e.g., production of wood and other materials) is considered subordinate to the principal aim.

19.12 Environmental Ethics and Resource Use

The resource consumption pattern of people in economically developed and developing countries differs radically. In developed countries, people have aspirations for better quality of life, and their resource demand is far more than necessary for reasonable living. Consequently, they exhaust resources and degrade the global environment seriously. On the other hand, people in developing countries have small resource need due to their simpler life style. But their exploding population, coupled with lower environmental awareness and growing desire to rapidly upgrade living conditions, leads to reckless destruction of resources. The resource use pattern of western countries, which is based on consumerism, is spreading fast in developing countries.

India is a unique country with a great cultural diversity, associated with all kinds of climates and rich flora and fauna. The human societies in our country have evolved within magnificient environments, and reverence to nature is inherent in our cultural ethos. The roots of ecological and environmental values are deep in our ancient Vedic literature and Upanishads. The *Atharva-Veda* solemnly recognises an enduring allegiance of human kind to Mother Earth. A stanza in *Isha-Upanishad* states : "The whole universe together with its creatures belongs to the Lord (Nature).... Let no one species encroach over the rights and privileges of other species. One can enjoy nature by giving up greed."

Living in harmony with nature has always been emphasised with the philosophy to take from nature only what we actually need and not more. '*Khsiti*' (Soil), '*Jal*' (water),.'*Pavan*' (energy), '*Gagan*' (space) and '*Samira*' (air) are recognised as the basic resources of the earth. All organisms including man are integral part of nature, returning all the nourishment borrowed from Mother Earth.

Our classical literature is abound with the message that resources should not be used wasted, but conserved. For example, Kautilya's famous treatise *Arthashashtra* describes what may be considered as the world's first forest conservation and wildlife management programme. Contemporary Mauryan kings maintained forests for different purposes, like elephant domestication, hunting, and forests as reserve. Through history, the Indian people have not been exploiters but utilisers of nature. Our country has been under the influence of humans and agriculture for about 10,000 years. Fortunately for us, the resource depletion has not been proportional to our very long history. This has been mainly due to the compassion for the living and the non-living and the principle of *Ahimsa puromo dharma* that are ingrained in our culture. There is a need to incorporate these principles in regulating resource use. Based on our cultural heritage and tradition, our resource utilisation should be optimised. We must recognise our responsibility to conserve earth's resources for future generations.

SUMMARY

Any component of the natural environment utilised by man is known as a natural resource. The natural resource can be a substance, an energy unit or a natural process, or phenomenon. Resources can be categorised as inexhaustible and exhaustible. Inexhaustible resources (e.g., solar energy, wind power) are available in unlimited quantities on the earth. Exhaustible resources have finite supply and can be either renewable or non-renewable. The growth and reproduction of renewable resources (e.g., products from forests, grasslands) can be successfully managed so that these resources are continuously regenerated. Non-renewable resources (e.g., biological species)

cannot be regained or reconstructed once they are used up. Amongst the earth's resources, soil, water, land, energy and mineral resources contribute significantly to human welfare.

Soil resource regulates the yield of biotic products in terrestrial ecosystems. Erosion by water and air causes a significant loss of soil fertility. Although world's freshwater reserves constitute only 2.5 per cent of the total water (rest being saline), yet they play significant role in global hydrological cycle. The world's use of water has been increasing, and agriculture and industries account for most of the water consumption. Water conservation practices are important to ensure water availability.

Among land resources the most important are : forests, grasslands and wetlands. World's forest cover has been shrinking rapidly, especially in the developing counties. Deforestation causes the extinction of plant, animal and microbial species and may induce regional and global climate change. Massive afforestation programmes are the need of the hour to save forest cover. Grasslands provide forage and habitat to domestic animals and wildlife, and grass cover effectively binds the soil with its highly branched fibrous root system. Wetlands (freshwater or salt water) provide crucial environmental services, like high productivity, control of floods, and serve as groundwater recharging areas.

Energy resources are non-renewable (e.g., fossil fuel, nuclear energy) or renewable (e.g., hydropower, wind, geothermal energy, ocean waves, tidal energy). Renewable energy generally causes much less negative environmental impact than fossil fuels or nuclear energy. Among various solar energy resources, biomass energy is most important. Various algae and animals form important marine resources. Minerals are non-renewable resources.

India is a unique country with a great cultural diversity, associated with all kinds of climates and rich flora and fauna. Living in harmony with nature has always been emphasised with the philosophy to take from nature only what we actually need and not more. We must conserve resources for our future generations.

EXERCISES

1. Fill in the blanks :
   (a) Most biotic resources are ___________.
   (b) Deforestation causes ___________ of plant, animal and microbial species.
   (c) Grassland with scattered trees is called ___________.
   (d) Rainwater harvesting is done to recharge ___________.
   (e) Wetlands may be either ___________ or ___________.
   (f) Biomass energy is ___________.
   (g) Agar is obtained from ___________.
   (h) Mine spoil can be restored by ___________.
2. Tick (✓) the correct answer. Soil erosion can be prevented by
   (a) Overgrazing
   (b) Removal of vegetation
   (c) Afforestation
   (d) Deforestation
3. Mild grazing in grassland by herbivores :
   (a) Retards growth of grasses
   (b) Arrests growth of grasses
   (c) Stimulates growth of grasses
   (d) Destroys vegetation

4. Deforestation generally decreases :
   (a) Rainfall
   (b) Soil erosion
   (c) Drought
   (d) Global warming
5. Forest area in India is about :
   (a) 9 per cent of geographical area
   (b) 19 per cent of geographical area
   (c) 29 per cent of geographical area
   (d) 37 per cent of geographical area
6. Which one of the following represents a renewable source of energy?
   (a) Petroleum
   (b) Coal
   (c) Nuclear fuel
   (d) Trees
7. Which of the following represents the regulative function of forest?
   (a) Storage and release of gases
   (b) Production of wood
   (c) Production of essential oils
   (d) Conservation of soil and water
8. In India, per capita forest area is :
   (a) 0.06 ha
   (b) 0.60 ha
   (c) 1.0 ha
   (d) 1.6 ha
9. Extensive planting of trees to increase forest cover is called :
   (a) Afforestation
   (b) Agro-forestry
   (c) Deforestation
   (d) Social forestry
10. Wetlands occupy :
   (a) 6 per cent of world's land
   (b) 10 per cent of world's land
   (c) 12 per cent of world's land
   (d) 14 per cent of world's land
11. Distinguish between the following :
   (a) Inexhaustible and exhaustible resources
   (b) Renewable and non-renewable resources
   (c) Afforestation and agro-forestry
12. Match the following items in Column I with items in Column II

	Column I		**Column II**
(i)	Soil	(a)	Recharge
(ii)	Groundwater	(b)	Rotational grazing
(iii)	Forest management	(c)	Reverine forest
(iv)	Grassland management	(d)	Taungya
(v)	Wetland	(e)	Erosion
		(f)	Energy

13. Distinguish between the following :
   (a) Freshwater wetlands and marine wetlands
   (b) Grasslands and wetlands
   (c) Deforestation and desertification
14. Explain why soil resource is important for human welfare.
15. What are the methods of conserving water resources?
16. What is the importance of forest resources?
17. How do we manage our grassland?
18. Why are wetlands considered ecologically important?
19. Explain the significance of biomass energy.
20. Describe major marine resources.

Chapter 20

Biodiversity

If you observe a patch of a forest, you may notice a large variety of plant life, ranging from a tiny grass to a huge tree. You may also observe a wide variety of animal life, from a tiny insect to a large mammal, such as an elephant, inhabiting the forest. Apart from plants and animals, there are numerous micro-organisms in the soil that you cannot see by naked eye. The occurrence of different kinds of organisms reflects the biological diversity or, in short, biodiversity of the forest patch. The term **biodiversity** refers to the totality of genes, species, and ecosystems of a region. From the previous chapters in this Unit, you know that all the species cannot occur at one place. Whether or not a species can occur on a site is determined by the environmental conditions of the site and the range of tolerance of the species. Therefore, if you visit a different patch of forest at some other place and compare its biodiversity with that of the previous one, you will find that both plant life as well as animal life are different. Thus, biodiversity differs from place to place. Taking into consideration the total habitats of plants and animals, one can arrive at the inference that the living world abounds with enormous biodiversity.

Biologically-rich and unique habitats are being destroyed, fragmented, and degraded due to problems caused by increasing human population, resource consumption and pollution. Biodiversity loss is now one of the world's most pressing crises. The primary reason for the concern is the realisation that biological diversity is being lost even before its size is known. Loss of biodiversity would check the evolutionary capability of biota to cope up with environmental changes. How to check the loss of species and erosion of gene pool is one of the major challenges to science. In this chapter, we shall study about the amazing biological diversity on Earth, and the dependence of human population on biodiversity for food and other necessities. The ways in which human activities are affecting biological diversity, causes of increased rate of extinction of species, and various approaches for conserving biological diversity also form a part of this chapter.

20.1 Magnitude of Biodiversity

Systematic work on identifying and naming species has been in progress for the last 250 years. But still, we have collected, described and named far less number of species than the actual number present. Table 20.1 gives a summary of the number of known species on the earth distributed among major taxonomic groups. The known and described number of species of all organisms on the earth is between 1.7 and 1.8 million, which is fewer than 15 per cent of the actual number. The predicted number of total species varies from 5 to 50 million and averages at 14 million. About 61 per cent of the known species are insects. Only 4650 species of mammals are known to science. A large number of plant species (2,70,000) and vertebrates are known. There are many more species that have not yet been described, especially in the tropics. Information about bacteria, viruses, protists and Archaea is just fragmentary. However, new species are being discovered faster than ever before due to the efforts of projects like Global Biodiversity

Table 20.1 : Approximate Numbers of Species which have been Described and Identified from all over the World

Group	Number of species
Higher Plants	2,70,000
Algae	40,000
Fungi	72,000
Bacteria (including cyanobacteria)	4,000
Viruses	1,550
Mammals	4650
Birds	9700
Reptiles	7150
Fish	26,959
Amphibians	4780
Insects	10,25,000
Crustaceans	43,000
Molluscs	70,000
Nematodes and worms	25,000
Protozoa	40,000
Others	1,10,000

Information Facility and the Species 2000. The number of species of different taxonomic groups, described from India, are shown in Figure 20.1.

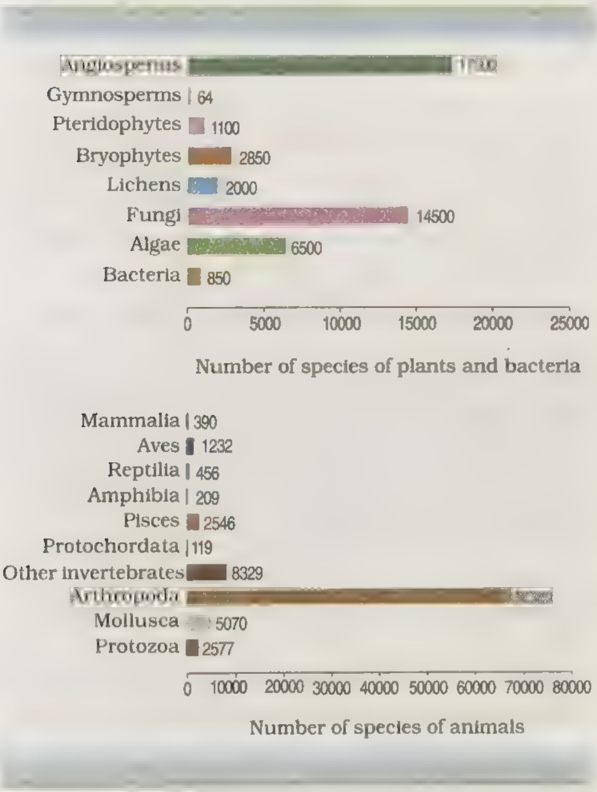


Fig. 20.1 Number of plant and animal species in different groups recorded in India

20.2 Levels of Biodiversity

There is a fascinating variety of organisms, complex ecological relationships among organisms, genetic diversity within species and a great variety of ecological systems. To develop conservation plans for biodiversity, we must be clear about the concept of biodiversity.

Biological diversity includes three hierarchical levels :

(i) Genetic diversity,
(ii) Species diversity, and
(iii) Community and ecosystem diversity.

These levels of biodiversity are interrelated, yet distinct enough to be studied separately to understand the interconnections that support life on earth.

Genetic Diversity

We know that each species, varying from bacteria to higher plants and animals, stores an immense amount of genetic information. For example, the number of genes is about 450-700 in Mycoplasma, 4000 in *Escherichia coli*, 13000 in *Drosophila melanogaster*, 32000-50000 in *Oryza sativa*, and 35000 to 45000 in *Homo sapiens sapiens*.

Genetic diversity refers to the variation of genes within species; the differences could be in alleles (different variants of same genes), in entire genes (the traits determining particular characteristics) or in chromosomal structures. The genetic diversity enables a population to adapt to its environment and to respond to natural selection. If a species has more genetic diversity, it can adapt better to the changed environmental conditions. Lower diversity in a species leads to uniformity, as is the case with large monocultures of genetically similar crop plants. This has advantage when increased crop production is a consideration, but can be a problem when an insect or a fungal disease attacks the field and poses a threat to the whole crop.

The amount of genetic variation is the basis of **speciation** (evolution of new species). It has a key role in the maintenance of diversity at

species and community levels. The total genetic diversity of a community will be greater if there are many species, as compared to a situation where there are only a few species. Genetic diversity within a species often increases with environmental variability.

Species Diversity

Species are distinct units of diversity, each playing a specific role in an ecosystem. Therefore, loss of species has consequences for the ecosystem as a whole. Species diversity refers to the variety of species within a region. Simplest measure of species diversity is **species richness**, i.e., the number of species per unit area. The number of species increases with the area of the site. Generally, greater the species richness, greater is the species diversity. However, number of individuals among the species may also vary, resulting into differences in **evenness**, or **equitability**, and consequently in diversity. Suppose, we are having three sample areas. In the sample area 1, there are three species of birds. Two species are represented by one individual each, while the third species has four individuals (Fig. 20.2). In the sample area 2 that has the same three species, each species is represented by two individuals. This sample area shows greater evenness, and there are equal chances for a species being represented in a sample. The sample area 2 will be considered more diverse than the first. In the sample area 3, the species are represented by an insect, a mammal and a bird. This sample area is most diverse as it comprises taxonomically unrelated species. In this example, we find equal number of species but varying number of individuals per species. In nature, both the number and kind of species, as well as the number of individuals per species vary, leading to greater diversity.

Fig. 20.2 *The different sample areas showing species richness (sample area 1), species evenness (sample area 2) and diversity due to taxonomically unrelated species (sample area 3)*

Community and Ecosystem Diversity

Diversity at the level of community and ecosystem has three perspectives. **Alpha diversity** (within-community diversity) refers to the diversity of organisms sharing the same community/habitat (Fig. 20.3). A combination of species richness and equitability/evenness is used to represent diversity within a community or habitat. Species frequently change when habitat or community changes. The rate of replacement of species along a gradient of habitats or communities is called **beta diversity** (between-community diversity). As shown in Figure 20.3, there are differences in species composition of communities along environmental gradients, e.g., altitudinal gradient, moisture gradient, etc. Higher

Fig. 20.3 *Three perspectives of diversity : alpha, beta and gamma diversity*

the heterogeneity in the habitats in a region or greater the dissimilarity between communities, higher is the beta diversity. Diversity of the habitats over the total landscape or geographical area is called **gamma diversity** (Fig. 20.3).

Ecosystem diversity describes the number of niches, trophic levels and various ecological processes that sustain energy flow, food webs and the recycling of nutrients. It has a focus on various biotic interactions and the role and function of keystone species. Studies in temperate grasslands have shown that diverse communities are functionally more productive and stable, even under environmental stresses such as prolonged dry conditions.

As discussed in earlier chapters of this Unit, the number of habitats or ecosystems can vary within a geographical area. We also know that savannas, rain forests, deserts, lakes and wetlands and oceans are major ecosystems, where species live and evolve. The number of habitats/ecosystems present in a region is also a measure of biodiversity.

In India, we are endowed with a rich diversity of the biogeographically distinct regions due to varying physical conditions and species groupings. The various biogeographical regions of India are shown in

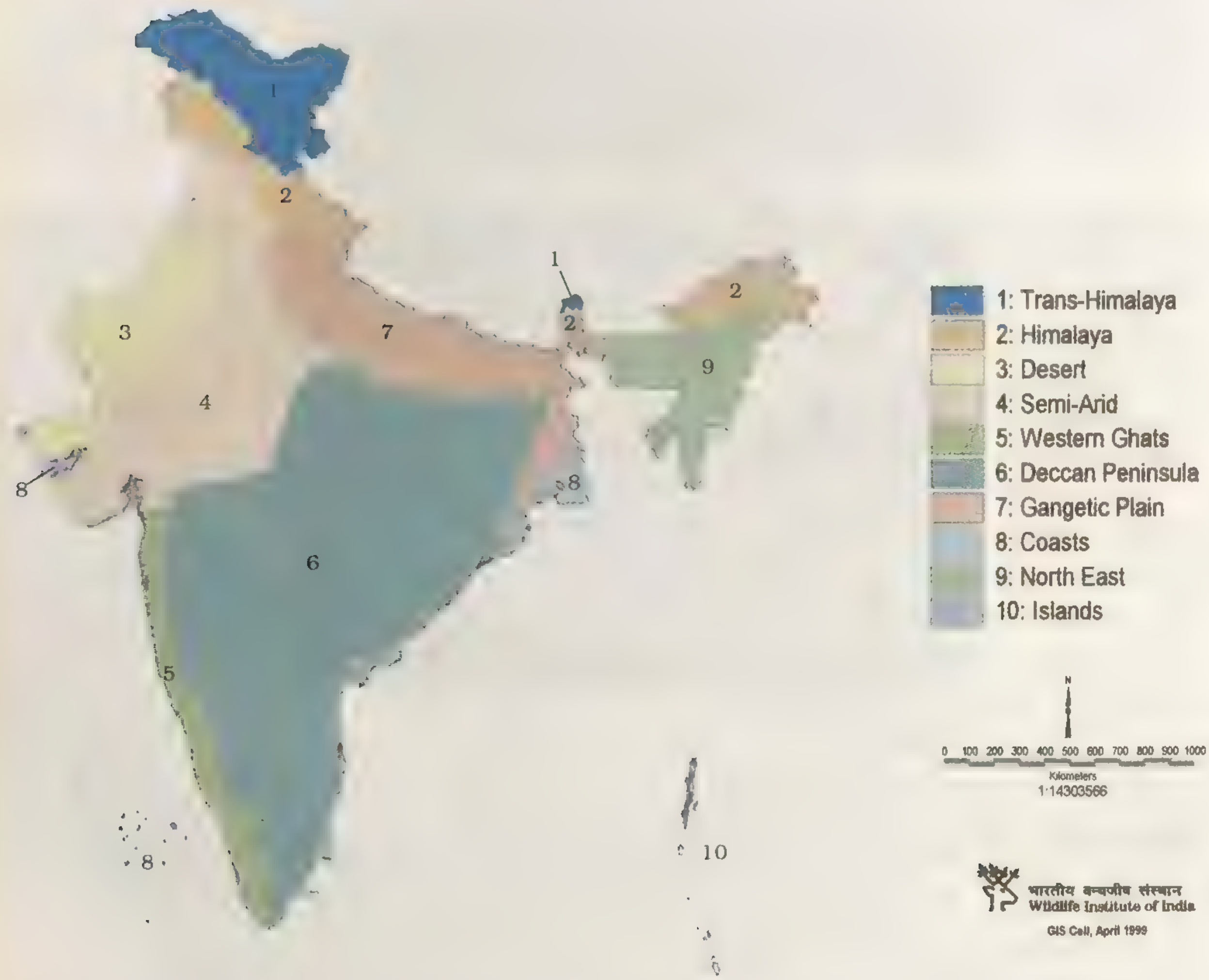


Fig. 20.4 *Biogeographical regions of India*

Figure 20.4. Among the biogeographical regions, Deccan peninsula has the most extensive coverage of the Indian landmass (42 per cent). The most biodiversity-rich zones, Western Ghats and north-east, account for 4 and 5.2 per cent of the geographical area, respectively. Each biogeographical zone has several habitats, biotic communities and ecosystems. A large number of species found in these zones are endemic or exclusive to India. About 33 per cent of the flowering plants recorded in India are endemic to our country. Indian region is also notable for endemic fauna. For example, out of the recorded vertebrates, 53 per cent freshwater fish, 60 per cent amphibians, 36 per cent reptiles and

10 per cent mammals are endemic. The endemics are concentrated mainly in north-east, Western Ghats, north-west Himalaya and Andaman and Nicobar Islands. A very high number of amphibian species are endemic to Western Ghats. However, the biological diversity of many ecosystems still remains poorly explored in India. These ecosystems include the deep oceans, wetlands and lakes, and habitats such as the tree canopy and soil of tropical rain forests.

20.3 Gradients of Biodiversity

Biodiversity varies with change in latitude or altitude. As we move from high to low latitudes (i.e., from the poles to the equator), broadly speaking, the biological diversity increases. While in the temperate region the climate is severe with short growing period for plants, in tropical rain forest the conditions are favourable for growth throughout the year. Favourable environmental conditions favour speciation, and make it possible for a larger number of species to occur and grow. For example, mean number of vascular plant species per 0.1 ha sample area in tropical rain forests varies from 118-236, whereas it is only in the range of 21-48 species in the temperate zones. As shown in Figure 20.5, such a correlation between diversity and latitude is also found for a wide variety of taxonomic groups, such as ants, birds, butterflies, and moths, etc.

Similarly, we generally notice a decrease in species diversity from lower to higher altitudes

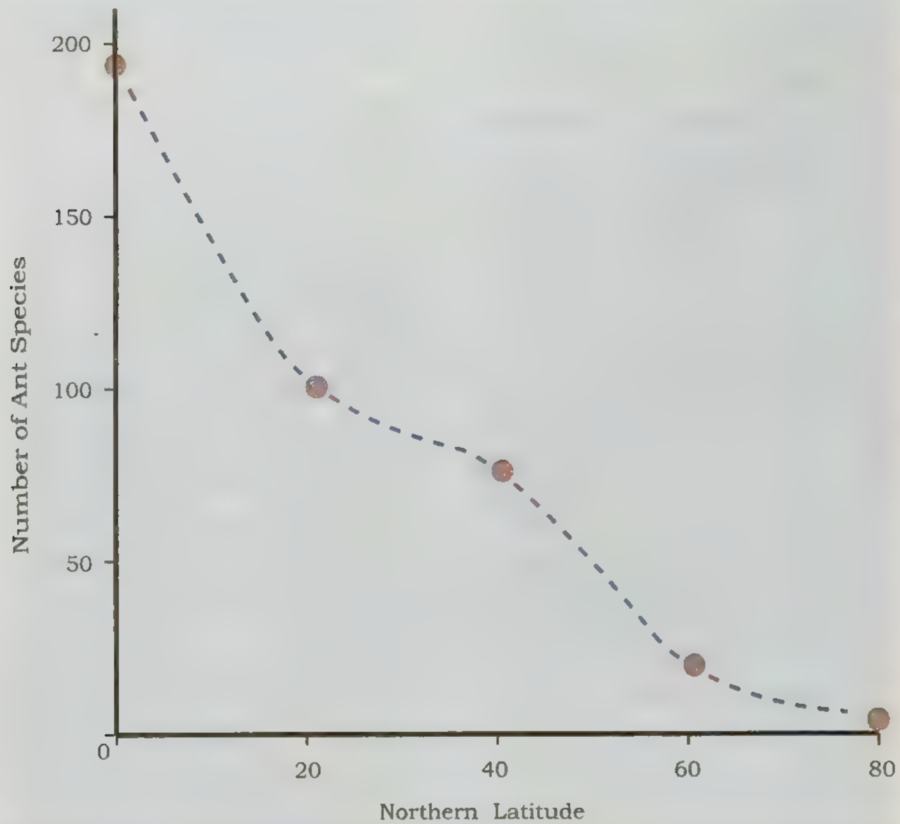


Fig. 20.5 *Decrease in number of ant species along the latitudinal gradient (from low to high latitude)*

on a mountain. A 1000 m increase in altitude results in a temperature drop of about 6.5°C. This drop in temperature and greater seasonal variability at higher altitudes are a major factor that reduces diversity. The latitudinal and altitudinal gradients of species diversity are two master gradients, although regional and taxa-related exceptions do occur. Also, it is expected that more complex and heterogeneous the physical environment, more complex and diverse will be the flora and fauna.

20.4 Uses of Biodiversity

Humans derive many direct and indirect benefits from the living world. Biodiversity is the source of food, medicines, pharmaceutical drugs, fibres, rubber and timber. The biological resources contain potentially useful resources as well. The diversity of organisms also provides many ecological services free of charge that are responsible for maintaining ecosystem health. The uses of biodiversity are briefly described below.

Source of Food and Improved Varieties

Biodiversity is of use to modern agriculture in three ways :

(i) as a source of new crops,
(ii) as a source material for breeding improved varieties, and
(iii) as a source of new biodegradable pesticides.

Of the several thousand species of edible plants, less than 20 plant species are cultivated to produce about 85 per cent of the world's food. Wheat, corn and rice, the three major carbohydrate crops, yield nearly two-third of the food sustaining the human population. Fats, oils, fibres, etc. are other uses for which more and more new species need to be investigated.

The domesticated species are crossbred with their wild relatives to improve their traits. Genes of wild species are used to confer new properties, such as disease resistance or improved yield in domesticated species. For example, rice grown in Asia is protected from the four main diseases by genes received from a single wild rice species (*Oryza nivara*) from India.

Drugs and Medicines

Biodiversity is a rich source of substances with therapeutic properties. Examples of plant-derived substances developed into valuable drugs are : Morphine (*Papaver somniferum*), used as an analgesic; Quinine (*Chinchona officinalis*) used for the treatment of malaria; and Taxol, an anticancer drug obtained from the bark of the yew tree (*Taxus brevifolia*, *T. baccata*). Currently, 25 per cent of the drugs in the pharmacy are derived from a mere 120 species of plants. But, throughout the world, traditional medicines make use of thousands of plant species.

Aesthetic and Cultural Benefits

Biodiversity has also great aesthetic value. Examples of aesthetic aspects include ecotourism, bird-watching, wildlife, pet keeping, gardening, etc. Throughout human history, people have related biodiversity to the very existence of human race through cultural and religious beliefs. In a majority of Indian villages and towns, plants like *Ocimum sanctum* (Tulsi), *Ficus religiosa* (Pipal), and *Prosopis cineraria* (Khejri) and various other trees are planted, which are considered sacred and worshipped by the people. Several birds, and even snake, have been considered sacred. Today, we continue to recognise plants and animals as symbols of national pride and cultural heritage.

Ecosystem Services

Biodiversity is essential for the maintenance of ecosystems and their sustainable utilsation. These services include maintenance of gaseous composition of the atmosphere, climate control by forests and oceanic systems, natural pest control, pollination of plants by insects and birds, formation and protection of soil, conservation and purification of water, and nutrient cycling, etc. These ecosystem services have been valued in the range of 16 to 54 trillion (10^{12}) US dollars per year.

20.5 Threats to Biodiversity

Important factors leading to extinction of species and consequent loss of biodiversity are : habitat loss and fragmentation; introduction of non-native (exotic) species; overexploitation; soil, water and atmospheric pollution; encroachment of forestland and deforestation.

Habitat Loss and Fragmentation

The destruction of habitats is the primary reason for the loss of biodiversity. When people cut down trees, fill a wetland, plough a grassland or burn a forest, the natural habitat of a species is changed or destroyed. These changes can kill or force out many plants, animals, and microorganisms, as well as disrupt complex interactions among the species. A forest patch surrounded by croplands, orchards, plantations, or urban areas is an example of fragmented habitats. With the fragmentation of a large forest tract, species occupying deeper parts of forests are the first to disappear. Overexploitation of a particular species reduces the size of its population to an extent that it becomes vulnerable to extinction.

Disturbance and Pollution

Communities are affected by natural disturbances, such as fire, tree fall, and defoliation by insects. Man-made disturbances differ from natural disturbances in intensity, rate and spatial extent. For example, man, by using fire more frequently may change species richness of a community. Then, some human impacts are new, never faced before by biota, e.g., the indiscriminate use of synthetic compounds, massive releases of radiations or spillover of oil in sea. These impacts lead to a change in the habitat quality. Pollution may reduce and eliminate populations of sensitive species. For example, pesticide linked decline of fish-eating birds and falcons. Lead poisoning is another major cause of mortality of many species, such as ducks, swans and cranes, as they take in the spent shotgun pellets that fall into lakes and marshes. Eutrophication (nutrient enrichment) of water bodies drastically reduces species diversity.

Introduction of Exotic Species

New species entering a geographical region are called exotic or alien species. Introduction of such invasive species may cause disappearance of native species through changed biotic interactions. Invasive species are considered second only to habitat destruction as a major cause of extinction of species. Exotic species are having large impact especially in island ecosystems, which harbour much of the world's threatened biodiversity. A few examples are :

(i) Nile perch, an exotic predatory fish introduced into Lake Victoria (South Africa) threatens the entire ecosystem of the lake by eliminating several native species of the small Cichlid fish species that were endemic to this freshwater aquatic system.

(ii) Water hyacinth (*Eichhornia*) clogs rivers and lakes and threatens the survival of many aquatic species in several tropical countries, including India.

(iii) *Lantana camara* has invaded many forest lands in different parts of India, and strongly competes with the native species.

Extinction of Species

Extinction is a natural process. Species have disappeared and new ones have evolved to take their place over the long geological history of the earth. It is useful to distinguish three types of extinction processes.

Natural extinction : With the change in environmental conditions, some species disappear and others, which are more adapted to changed conditions, take their place. This loss of species which occurred in the geological past at a very slow rate, is called natural or background extinction.

Mass extinction : There have been several periods in the earth's geological history when large number of species became extinct because of catastrophes. Mass extinctions occured in millions of years.

Anthropogenic extinction : An increasing number of species are disappearing from the face of the earth due to human activities. This man-made mass extinction represents a very severe depletion of biodiversity, particularly because it is occurring within a short period of time.

The World Conservation Monitoring Centre has recorded that 533 animal species (mostly vertebrates) and 384 plant species (mostly flowering plants) have become extinct since the year 1600. More species have gone extinct from the islands than from the mainland or the oceans.

The current rate of extinction is 1000 to 10000 times higher than the background rate of extinction. Some interesting observations about the current loss of species are :

(i) From ten high-diversity localities in tropical forests covering 300,000 km^2, some 17,000 endemic plant species and 350,000 endemic animal species could be lost in near future.

(ii) The tropical forests alone are losing roughly 14,000-40,000 species per year (or 2-5 species per hour).

(iii) The earth may lose up to 50 per cent of the species by the end of the 21^{st} century, if the current rate of loss continues.

Susceptibility to Extinction

The characteristics of species particularly susceptible to extinction are : large body size (Bengal tiger, lion and elephant); small population size and low reproductive rate (Blue whale and Giant panda). Feeding at high trophic levels in the food chain (Bengal tiger and Bald eagle), fixed migratory routes and habitat (Blue whale and Whooping crane) and localised and narrow range of distribution (woodland caribou; many island species) also make the species susceptible to extinction.

The IUCN Red List Categories

The IUCN Red List is a catalogue of taxa that are facing the risk of extinction. It is important to understand that the Red List aims to impart information about the urgency and scale of conservation problems to the public and policy makers. The uses of the Red List are :

(i) Developing awareness about the importance of threatened biodiversity;

(ii) Identification and documentation of endangered species;

(iii) Providing a global index of the decline of biodiversity;

(iv) Defining conservation priorities at the local level and guiding conservation action.

The World Conservation Union (formerly known as International Union for the Conservation of Nature and Natural Resources, IUCN) has recognised eight Red List Categories of species : *Extinct, Extinct in the Wild, Critically Endangered, Endangered, Vulnerable, Lower Risk, Data Deficient,* and *Not Evaluated*. These categories are defined in Table 20.2.

Table 20.2 : The IUCN Red list Categories

Red List Category	Definition
Extinct	A taxon is Extinct when there is no reasonable doubt that the last individual has died.
Extinct in the wild	A taxon is Extinct in the wild when exhaustive surveys, in known and/or expected habitats, have failed to record an individual.
Critically Endangered	A taxon is Critically Endangered when it is facing an extremely high risk of extinction in the wild in the immediate future.
Endangered	A taxon is Endangered when it is not Critically Endangered, but is facing a very high risk of extinction in the wild in the near future.
Vulnerable	A taxon is Vulnerable when it is not Critically Endangered or Endangered, but is facing a high risk of extinction in the wild in the medium-term future.
Lower Risk	A taxon is Lower Risk when it has been evaluated and does not satisfy the criteria for Critically Endangered, Endangered or Vulnerable.
Data Deficient	A taxon is Data Deficient when there is inadequate information to make a direct, or indirect, assessment of its risk of extinction.
Not Evaluated	A taxon is Not Evaluated when it has not yet been assessed against the above criteria.

The species which are threatened with extinction are included in Vulnerable, Endangered, or Critically Endangered categories.

Species with small world populations that are not at present endangered or vulnerable, but are at risk, are called **rare**. These species are usually localised within restricted geographical areas or habitats, or are thinly scattered over a more extensive range.

The IUCN Red List System was initiated in 1963, and since then, evaluation of the conservation status of species and subspecies is continuing on a global scale. The 2000 IUCN Red List is the most comprehensive inventory of the global conservation status of plant and animal species. It uses a set of criteria, relevant to all species and all regions of the world, to evaluate the extinction risk of species and subspecies. The 2000 Red List contains assessments of more than 18,000 species, 11,000 of which are threatened.

The Red List also provides information to international agreements, such as the Convention on Biological Diversity and the Convention on International Trade in Endangered Species of Wild Fauna and Flora.

Status of threatened species : There are 11,046 species (5,485 animals, and 5,611 plants) listed as threatened (Critically Endangered, Endangered, or Vulnerable) on the 2000 Red List. Of these, 1,939 are listed as Critically Endangered (925 animals, and 1,014 plants). The percentages of threatened species of Angiosperms and four vertebrate groups categorised as Critically Endangered, Endangered, Vulnerable and at Lower Risk are shown in Figure 20.6. As you can see from this figure, of the species evaluated for risk in these major groups, 9-16 per cent are critically endangered, and 34-51 per cent are vulnerable.

According to the Red List, in India, 44 plant species are critically endangered, 113 endangered and 87 vulnerable. Amongst animals, 18 are critically endangered, 54 endangered and 143 vulnerable (Fig. 20.7). Some examples of threatened species in India are given in Table 20.3.

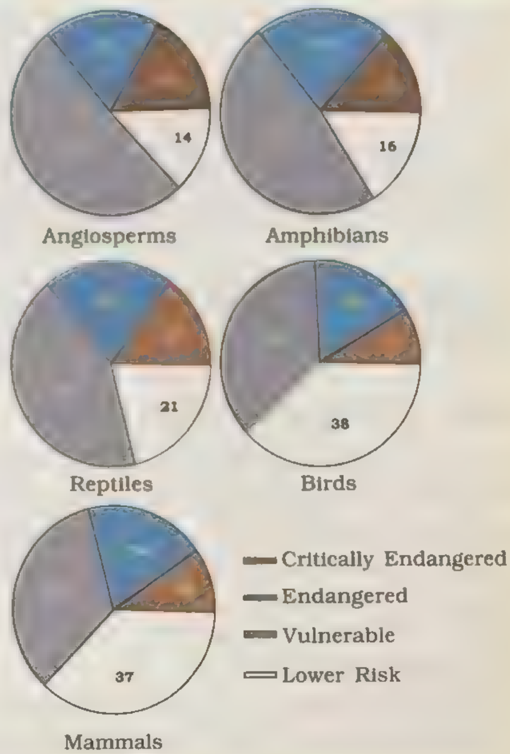


Fig. 20.6 *The percentage of threatened angiosperms, amphibians, reptiles, birds and mammals categorised as Critically Endangered, Endangered, Vulnerable and at Lower Risk*

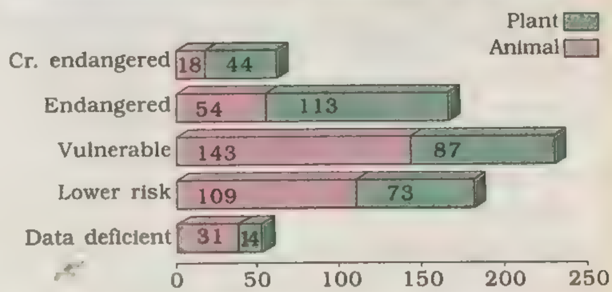


Fig. 20.7 *The number of plant and animal species of various threat categories in India*

Table 20.3 : Examples of Threatened Species in India

Category	Plants	Animals
Critically Endangered	*Berberis nilghiriensis*	*Sus salvanius* (Pigmy hog)
Endangered	*Bentinckia nicobarica*	*Ailurus fulgens* (Red Panda)
Vulnerable	*Cupressus cashmeriana*	*Antilope cervicapra* (Black buck)

20.6 Conservation of Biodiversity

We know that ecosystems are undergoing change due to pollution, invasive species, overexploitation by humans, and climate change. Most people are beginning to recognise that diversity at all levels – gene pool, species and biotic community – is important and needs to be conserved.

There is also an ethical imperative of stewardship, i.e., we have a moral duty to look after our planet and pass it on in a good health to our future generations. We should not deprive the future generations from the economic and aesthetic benefits that they can derive from biodiversity. The decisions we make now, as individuals and as a society, will determine the diversity of genes, species and ecosystems that remain in future. We may appreciate the fact that the most effective and efficient mechanism for conserving biodiversity is to prevent further destruction or degradation of habitats by us. We require more knowledge to conserve biodiversity in reduced space and under increased pressure of human activities.

There are two basic strategies of biodiversity conservation, *in situ* (on site) and *ex situ* (off site).

In situ Conservation Strategies

The *in situ* strategies emphasise protection of total ecosystems. The *in situ* approach includes protection of a group of typical ecosystems through a network of protected areas.

Protected Areas : These are areas of land and/or sea, especially dedicated to the protection and maintenance of biological diversity, and of natural and associated cultural resources. These are managed through legal or other effective means. Examples of protected areas are National Parks, and Wildlife Sanctuaries. The earliest national parks, the Yellowstone in USA and the Royal near Sydney, Australia, were chosen because of their scenic beauty and recreational values. Many similar areas throughout the world now protect rare species or wilderness areas. World Conservation Monitoring Centre has recognised 37,000 protected areas around the world. As of September 2002, India has 581 protected areas (89 National Parks and 492 Wildlife Sanctuaries), covering 4.7 per cent of the land surface, as against 10 per cent internationally suggested norm. The Jim Corbett National Park was the first National Park established in India.

Some of the main benefits of protected areas are :

(i) maintaining viable populations of all native species and subspecies;
(ii) maintaining the number and distribution of communities and habitats, and conserving the genetic diversity of all the present species;
(iii) preventing human-caused introductions of alien species; and
(iv) making it possible for species/habitats to shift in response to environmental changes.

Biosphere Reserves : Biosphere reserves are a special category of protected areas of land and/or coastal environments, wherein people are an integral component of the system. These are representative examples of natural biomes and contain unique biological communities. The concept of Biosphere Reserves was launched in 1975 as a part of UNESCO's Man and Biosphere Programme, dealing with the conservation of ecosystems and the genetic resources contained therein. Till May 2002, there were 408 biosphere reserves located in 94 countries. There are 13 biosphere reserves in India and are shown in Figure 20.8. A bioshphere reserve may incorporate within its limit existing or proposed national parks, sanctuaries and other protected areas. A Biosphere Reserve consists

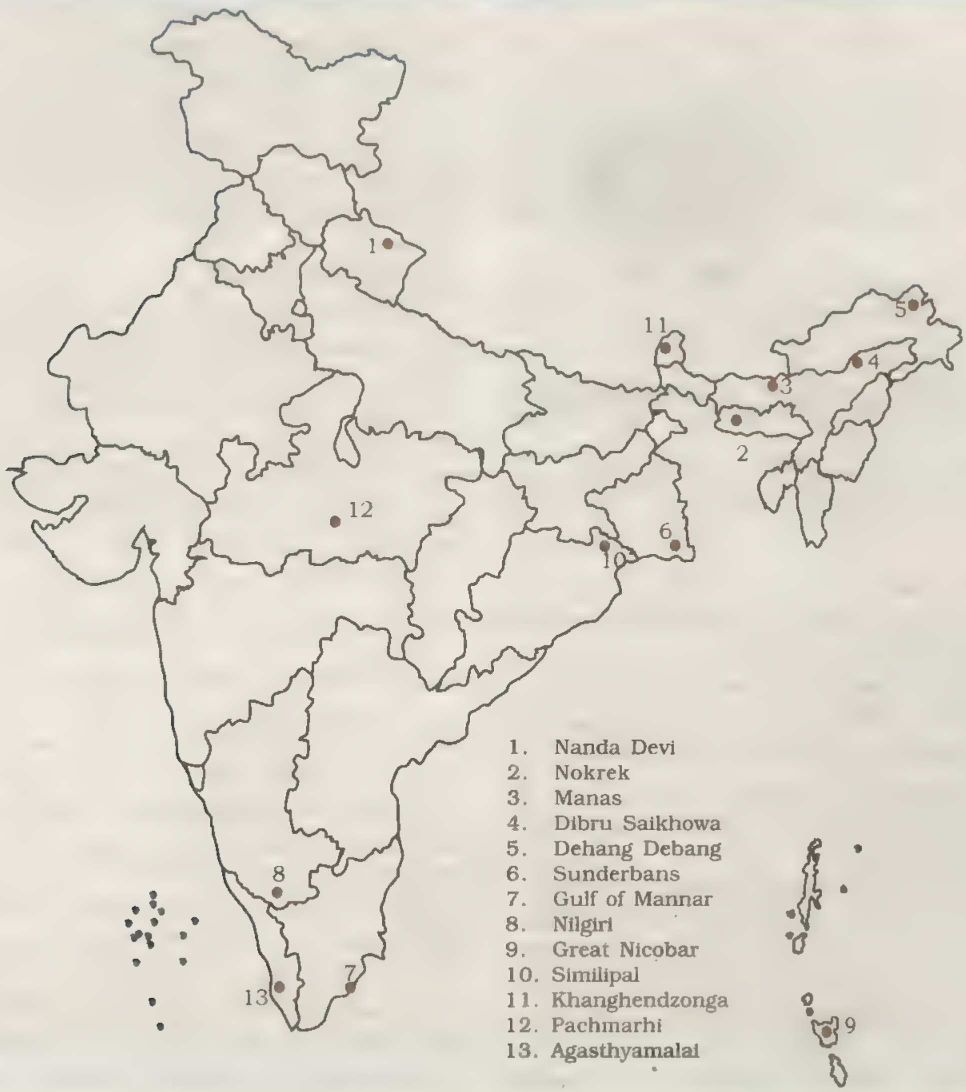


Fig. 20.8 *The Biosphere Reserves in India (Courtesy : Dr. G.S. Rawat)*

of core, buffer and transition zones (Fig. 20.9). The **natural** or **core zone** represents an undisturbed or least disturbed area of representative ecosystem. The **buffer zone** surrounds the core zone, and is meant for demonstration research and educational activities. The **transition zone**, the outermost part of the Biosphere Reserve, is an area of active cooperation between reserve management and the local people, wherein activities like settlements, cropping, forestry and recreation and other economic uses continue in harmony with conservation goals.

The main functions of biosphere reserves are :

(i) **Conservation** : To ensure the conservation of landscapes, ecosystems, species and genetic resources. It also encourages traditional resource use.

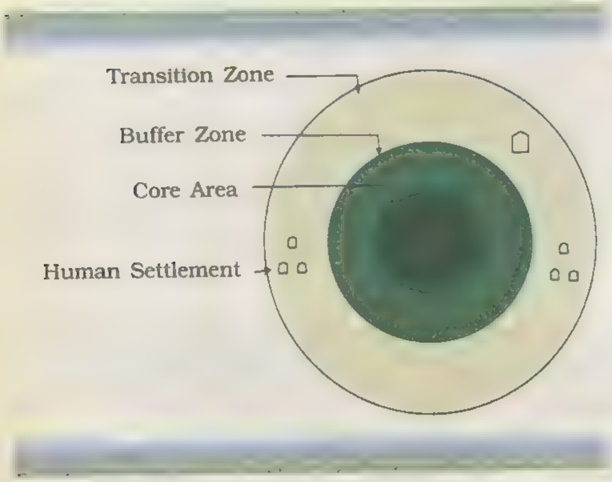


Fig. 20.9 *The zonation in a terrestrial Biosphere Reserve*

(ii) **Development** : To promote economic development which is culturally, socially and ecologically sustainable.

(iii) **Scientific research, monitoring and education** : The aim is to provide support for research, monitoring, education and information exchange related to local, national and global issues of conservation and development.

Sacred forests and sacred lakes : A traditional strategy for the protection of biodiversity has been in practice in India and some other Asian countries in the form of **sacred forests**. These are forest patches of varying dimensions protected by tribal communities due to religious sanctity accorded to them. The sacred forests represent islands of pristine forests (most undisturbed forests without any human impact) and have been free from all disturbances; though these are frequently surrounded by highly degraded landscapes. In India, sacred forests are located in several parts, e.g., Karnataka, Maharashtra, Kerala, Meghalaya, etc., and are serving as refugia for a number of rare, endangered and endemic taxa. Similarly, several water bodies (e.g., Khecheopalri lake in Sikkim) have been declared sacred by the people, leading to protection of aquatic flora and fauna.

Ex situ Conservation Strategies

The *ex situ* conservation strategies include botanical gardens, zoos, conservation stands, and gene, pollen, seed, seedling, tissue culture and DNA banks. Seed gene banks are the easiest way to store germplasm of wild and cultivated plants at low temperature in cold rooms. Preservation of genetic resources is carried out in field gene banks under normal growing conditions.

In vitro conservation, especially by **cryopreservation** in liquid nitrogen at a temperature of $-196°C$, is particularly useful for conserving vegetatively propagated crops like potato. Cryopreservation is the storage of material at ultra-low temperature either by very rapid cooling (used for storing seeds), or by gradual cooling and simultaneous dehydration at low temperature (used for tissue culture). The material can be stored for a long period of time in compact, low maintenance refrigeration units.

Conservation of biological diversity in botanical gardens is already in practice. There are more than 1500 botanical gardens and arboreta (botanical gardens where specific tree and shrub species are cultivated) in the world containing more than 80,000 species. Many of these now have seed banks, tissue culture facilities and other *ex situ* technologies. Similarly, there are more than 800 professionally managed zoos around the world with about 3,000 species of mammals, birds, reptiles and amphibians. Many of these zoos have well-developed captive breeding programmes.

The conservation of wild relatives of crop plants and the off-site conservation of crop varieties or cultures of micro-organisms provides breeders and genetic engineers with a ready source of genetic material. Plants and animals conserved in botanical gardens, arboreta, zoos and aquaria can be used to restore degraded land, reintroduce species into wild, and restock depleted populations.

20.7 Hot Spots of Biodiversity

Biodiversity is not uniformly distributed across the geographical regions of the earth.

Certain regions of the world are mega diversity zones where a very large number of species are found. For example, India accounts for only 2.4 per cent of the land area of the world, but it contributes approximately 8 per cent species to the global diversity.

Norman Myers developed the **hot spots** concept in 1988 to designate priority areas for *in situ* conservation. The hot spots are the richest and the most threatened reservoirs of plant and animal life on earth. The key criteria for determining a hot spot are :

(i) Number of endemic species, i.e., the species which are found nowhere else, and

(ii) Degree of threat, which is measured in terms of habitat loss.

Twenty-five terrestrial hot spots for conservation of biodiversity have been identified worldwide. Their approximate locations are shown in Figure 20.10. These hot spots together, now cover 1.4 per cent of the earth's land area. Tropical forests appear in 15 hot spots, Mediterranean-type zones in 5, and 9 hot spots are mainly or completely made up of islands. As many as 16 hot spots are in the tropics. About 20 per cent of the human population lives in the hot-spot regions.

Of the 25 hot spots of the world, two (Western Ghats and Eastern Himalayas) are located in India. These areas are rich in flowering plants, also in reptiles, amphibians, swallow-tailed butterflies and

1. Tropical Andes, 2. Mesoamerica, 3. Caribbean, 4. Brazil's Atlantic Forests, 5. Choco/Darien/Western Ecuador, 6. Brazil's Cerrado, 7. Central Chile, 8. California Floristic Province, 9. Madagascar, 10. Eastern Arc & Coastal Forests of Tanzania/Kenya, 11. West African Forests, 12. Cape Floristic Province, 13. Succulent Karoo, 14. Mediterranean Basin, 15. Caucasus, 16. Sundland, 17. Wallacea, 18. Philippines, 19. Indo-Burma, 20. South-Central China, 21. Western Ghats/Sri Lanka, 22. Southwest Australia, 23. New Caledonia, 24. New Zealand, 25. Polynesia/Micronesia.

***Fig. 20.10** The terrestrial biodiversity hot spots*

some mammals; and also show a high degree of endemism.

The eastern Himalayan hot spot extends to the north-eastern India and Bhutan. The temperate forests are found at altitudes of 1780 to 3500 meters. Many deep and semi-isolated valleys found in this region are exceptionally rich in endemic plant species. Besides being an active centre of evolution and rich diversity of flowering plants, the numerous primitive angiosperm families (e.g., Magnoliaceae and Winteraceae) and primitive genera of plants, like *Magnolia* and *Betula*, are found in eastern Himalaya.

The Western Ghat region lies parallel to the western coast of Indian peninsula for almost 1600 km, in Maharashtra, Karnataka, Tamil Nadu and Kerala. The forests at low elevation (500 m above mean sea level) are mostly evergreen, while those found at 500-1500 meter height are generally semi-evergreen forests. The Agasthyamalai hills, the Silent Valley and the new Amambalam Reserve, are the main centres of diversity.

20.8 International Efforts for Conserving Biodiversity

The Earth Summit held in 1992 at Rio de Janeiro (Brazil) resulted into a Convention on Biodiversity, which came into force on 29 December, 1993. The Convention on has three key objectives :

(i) Conservation of biological diversity.
(ii) Sustainable use of biodiversity and
(iii) Fair and equitable sharing of benefits arising out of the utilisation of genetic resources.

The World Conservation Union and the World Wide Fund for Nature (WWF) support projects worldwide to promote conservation and appropriate development of Biosphere Reserves.

20.9 Biodiversity Conservation in India

Indian region contributes significantly to global biodiversity. India is a homeland of 167 cultivated species and 320 wild relatives of crop plants. It is the centre of diversity of

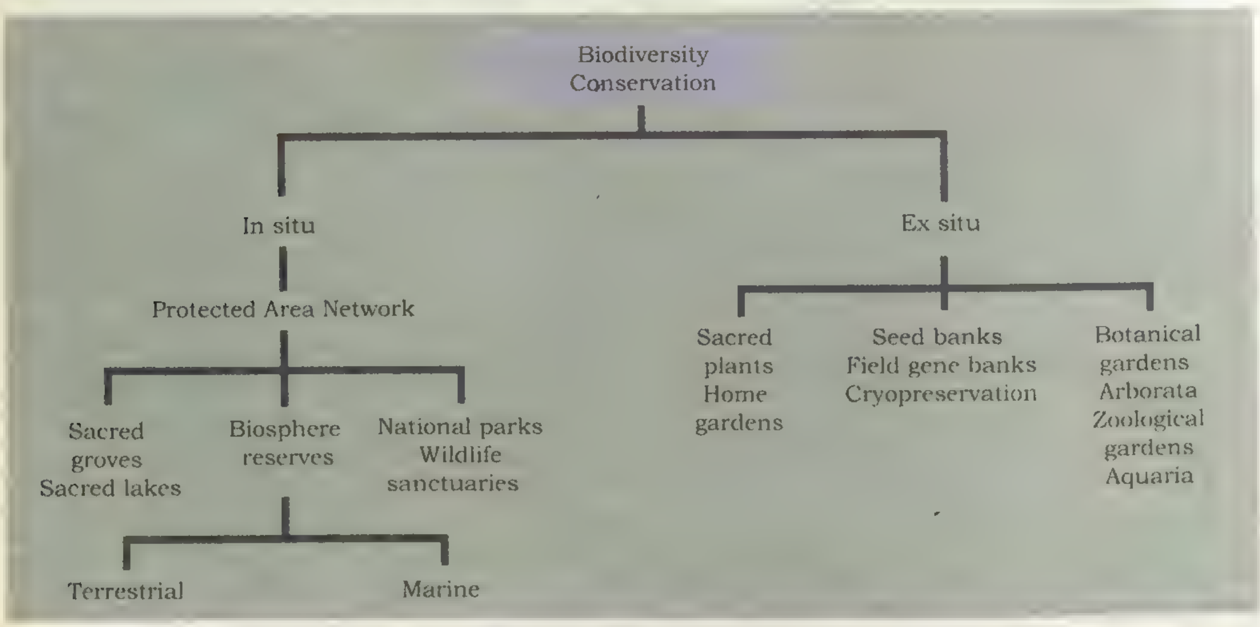


Fig. 20.11 The in situ and ex situ approaches of conserving biodiversity in India

animal species (zebu, mithun, chicken, water buffalo, camel); crop plants (rice, sugarcane, banana, tea , millet); fruit plants and vegetables (mango, jackfruit, cucurbits), edible dioscoreas, alocasia, colocasia; spices and condiments (cardamom, black pepper, ginger, turmeric); and bamboos, brassicas, and tree cotton. India also represents a secondary centre of domestication for some animals (horse, goat, sheep, cattle, yak, and donkey) and plants (tobacco, potato and maize).

The biodiversity management systems for conserving biodiversity in India are shown in Figure 20.11. The *in situ* conservation of biodiversity is being carried out through Biosphere Reserves, National Parks, Wildlife Sanctuaries and other protected areas by the Ministry of Environment and Forests (see section 20.6 of this chapter). The joint forest management systems involve forest departments and local communities. This enables the tribal people and local communities to have access to non-wood forest products, and at the same time protect the forest resources.

The National Bureaus of Plant, Animal and Fish Genetic Resources have a number of programmes to collect and conserve the germplasm of plants and animals in seed gene banks, and field gene banks for *in vitro* conservation. Botanical and zoological gardens have large collections of plant and animal species in different climatic regions of India.

The land races and diverse food and medicinal plants are also being conserved successfully by the tribal people and women working individually, or with various non-governmental agencies. The women particularly have an important role in the conservation of agrobiodiversity. In India, a programme is underway to develop a system of community registers of local informal innovations related to the genetic resources, as well as natural resource management in general.

SUMMARY

Biodiversity refers to the totality of genes, species, and ecosystems of a region. Biodiversity has many medicinal and economic uses. Genes of wild species are used to confer new properties, such as disease resistance or improved yield in domesticated species. Biodiversity also provides valuable indirect services through natural ecosystems. The total number of species on the Earth is estimated to range from 5-50 million, but only about 1.8 million species have so far been described. Biodiversity has three levels, (i) genetic, (ii) species, and (iii) community and ecosystem. Species are distinct units of diversity and each species plays a specific role in an ecosystem. The diversity within a species often increases with environmental variability. Species diversity refers to the variety of species within a region. Within-community diversity is called alpha diversity, between-communities beta diversity, and overall diversity of a region is known as gamma diversity. Biodiversity increases from poles toward equator, and from high elevations to low elevations.

Habitat loss and fragmentation, disturbance and introduction of alien species pose greatest threats to biodiversity. Invasive species are now second only to habitat destruction as a major cause of extinction of species. Exotic species especially are having large impacts in island ecosystems, which harbour much of the world's threatened biodiversity. In recent times, humans

have caused the extinction of many species and the rate of species loss is increasing. It is estimated that 14,000-40,000 species are being lost per year from the tropical forests alone.

The categories for species threatened with extinction include Vulnerable, Endangered, and Critically Endangered. The 2000 IUCN Red List is the world's most comprehensive inventory of the global conservation status of threatened plant and animal species. It is important to ensure the conservation of landscapes, ecosystems, species and genetic resources. Conservation strategies include *in situ* (on-site) and *ex situ* (off-site) approaches. Protected Area Network includes national parks, wildlife sanctuaries, and biosphere reserves, etc. Sacred groves or sacred forests are traditionally protected areas, which shelters a number of rare and endangered taxa. Twenty five hot spots of terrestrial biodiversity have been identified, of which two are in India. Convention on Biodiversity is an important international instrument promoting biodiversity conservation globally. IUCN and WWF are among the leading international organisations concerned with biodiversity conservation.

EXERCISES

1. What is biodiversity? Why has it become important recently?
2. Explain what is meant by species diversity.
3. What kinds of threats to the biodiversity may lead to its loss?
4. How is diversity at all levels generally conserved?
5. Broadly classify the extinction processes.
6. Write short notes on the following :
   (a) *Ex-situ* conservation
   (b) Hot spots of biodiversity
   (c) Biosphere reserves
   (d) IUCN Red List
   (e) Protected areas
7. Match the words in Column I with those in Column II.

	Column I		**Column II**
(i)	13000 genes	(a)	*Lantana camara*
(ii)	Anticancer drug	(b)	*Magnolia*
(iii)	Exotic species	(c)	*Drosophila melanogaster*
(iv)	Primitive genes	(d)	Humans
(v)	35000-45000 genes	(e)	Yew tree

8. The Earth Summit held at Rio de Janeiro in 1992 resulted into :
   (a) Compilation of Red List
   (b) Establishment of Biosphere Reserves
   (c) Convention on Biodiversity
   (d) IUCN.
9. Fill in the blanks in the following :
   (a) Biodiversity refers to the totality of __________, ________, and __________ of a region.
   (b) Within-community diversity is called ________________.
   (c) ________________ are traditional protected areas.

(d) Exotic species have a large impact, especially in __________ ecosystems.
(e) Between-community diversity is called _______.
(f) _________ and ________ in India are among the 25 global biodiversity hot spots.

10. Approximate percentage of endemic flowering plants in India is :
(a) 23
(b) 33
(c) 53
(d) 63

11. Fill in the blanks in the following :
(a) Biodiversity increases from the _______ to the equator.
(b) ______ animal species and _____ plant species in India are characterised as Critically Endangered in the Red List.
(c) As of September 2002, India had ____ protected areas.
(d) The core area in a Biosphere Reserve is surrounded by the _____ zone which, in turn, is surrounded by _____ zone.

12. What are the three major threat categories of species? Describe with examples.

13. Write an explanatory note on the efforts for conservation of biodiversity in India.

14. How is biodiversity distributed along major environmental gradients?

Chapter 21

Pollution and Global Environmental Change

In the earlier Chapters, you have read about the population, biotic community and delicately balanced functioning of ecosystem. You have studied in Chapter 19 that increased resource use by people, depletion of fossil fuel reserves, and the large scale changes in land use systems are having a large impact on all components of the environment. **Pollution** is an undesirable change in physical, chemical or biological characteristics of our air, land or water, caused by excessive accumulation of **pollutants** (substances causing pollution). These changes will waste or deteriorate our raw-material resources and the environment. Pollution adversely affects biological species, including humans. It damages our industrial processes, living conditions and cultural assets. Other significant changes brought about through human activities are changes in the lower atmosphere. These occur due to the increase in concentration of carbon dioxide and other greenhouse gases, and the depletion of stratospheric ozone layer. These environmental changes, occurring on a global scale, are influencing the air, water, land resources, biological diversity as well as human health. In this chapter, we will read about : (i) the causes, effects and control of pollution, (ii) the implications of global environmental changes due to increasing concentration of greenhouse gases, and (iii) the depletion of ozone in the stratosphere and its possible effects.

21.1 Kinds of Pollution

Pollution can be classified in many ways. On the basis of part of environment where it occurs most (atmosphere, hydrosphere and lithosphere), it can be classified as **air pollution**, **water pollution** and **soil pollution**. In terms of origin, pollution may be **natural** (e.g., volcanic eruptions which add tons of toxic gases and particulate matter in the environment), or **anthropogenic** (man-made, such as industrial pollution, agricultural pollution, etc.). According to the physical nature of the pollutants, the categories include : gases, particulate matter, temperature, noise, radioactivity, etc. These categories can be named as **gaseous pollution**, **dust pollution**, **thermal pollution**, **noise pollution**, **radioactive pollution**, etc.

From the ecosystem viewpoint, pollutants can be categorised into **non-biodegradable** and **biodegradable** pollutants. Non-biodegradable materials, such as chlorinated hydrocarbon pesticides (dichloro diphenyl trichloro ethane or DDT, benzene hexachloride or BHC, etc.), waste plastic bottles, polyethylene bags, used soft-drink cans, etc. are either not degraded, or degraded only very slowly by decomposers in the nature. Therefore, non-biodegradable pollutants are difficult to manage, and in most cases there is no treatment process to handle the anthropogenic input of such materials in the ecosystem.

Biodegradable pollutants, such as market garbage, livestock wastes, municipal sewage, etc., on the other hand, can be decomposed efficiently by the decomposers. Therefore, biodegradable pollutants are easily manageable by natural processes or in engineered systems such as the waste treatment plants. If managed

properly, biodegradable wastes can be turned into useful resources.

21.2 Air Pollution : Sources, Types and Effects

Degradation of air quality and natural atmospheric conditions constitute air pollution. An air pollutant may be a gas or particulate matter (i.e., suspended aerosols composed of solids and liquids). Concentrations of atmospheric pollutants depend mainly on the total mass emitted into the atmosphere, and the atmospheric conditions that affect their fate and transport. Most of the air we breathe is elemental O_2 and N_2. About 1 per cent is composed of other constituents, such as CO_2 and water vapour. A small part of this 1 per cent may, however, be air pollutants, including gases and particulate matter. Even such a small concentration may be extremely harmful to life and property.

Natural sources of air pollution include pollen, dust and smoke (from forest fires and volcanic ash) which are emitted into the atmosphere. Anthropogenic air pollutants enter the atmosphere from fixed and mobile sources. **Fixed sources** include large factories, electrical power plants, mineral smelters and different small-scale industries, while **mobile sources** include all sorts of transport vehicles moving by road, rail or air.

Air pollutants can be classified into two categories, *viz.*, **primary** and **secondary** air pollutants. Primary pollutants enter the atmosphere directly from various sources. Secondary pollutants are formed during chemical reactions between primary air pollutants and other atmospheric constituents, such as water vapour. Generally, these reactions occur in the presence of sunlight.

Primary Air Pollutants and their Effects

Amongst the primary air pollutants, most important are particulate matter, carbon monoxide (CO), hydrocarbons (HCs), sulphur dioxide (SO_2), and nitrogen oxides (NO_x).

Particulate matter comprises solid particles or liquid droplets (aerosols) small enough to remain suspended in air; examples are soot, smoke, dust, asbestos fibres, pesticides, some metals (including Hg, Pb, Cu and Fe), and also biological agents like tiny dust mites, spores and pollen. Atmospheric particles having diameter ≥ 10 µm, generally settle out in less than a day, whereas particles with diameters 1 µm or less can remain suspended in air for weeks. Suspended particulate matter in the lower atmosphere (troposphere) causes and aggravates human respiratory illness, like asthma, chronic bronchitis, etc. When accumulated in the upper atmosphere (stratosphere), particulate matter may significantly alter the radiation and thermal budgets of the atmosphere, lowering the temperature at the earth's surface.

Carbon monoxide (CO) is a product of incomplete combustion of fossil fuels. Nearly 50 per cent of all CO emission originates from automobiles. It is also present in cigarette smoke. CO is short-lived in the atmosphere and gets oxidised to CO_2. Carbon monoxide is highly poisonous to most animals. When inhaled, CO reduces the oxygen carrying capacity of blood.

Hydrocarbons (HCs) or **volatile organic carbons (VOCs)** are compounds composed of hydrogen and carbon. HCs are produced naturally during decomposition of organic matter. Methane (CH_4), the most abundant hydrocarbon in the atmosphere, is evolved from soil microbes (methanogens) in flooded rice fields and swamps. Benzene and its derivatives, such as formaldehyde, are carcinogenic (substance that causes cancer). Formaldehyde emitted from indoor sources, such as newly-manufactured carpeting, causes indoor pollution. Some relatively reactive HCs contribute to the generation of secondary pollutants. HCs are also generated during the burning of fossil fuels (coal and petroleum).

Sulphur dioxide (SO_2) is the major constituent in the emission when sulphur-containing coal is burnt. Ore smelters and oil refineries also emit significant amounts of SO_2. A high concentration of SO_2 in ambient air causes severe respiratory problems. Exposure to high SO_2 concentration is also harmful to plants.

Nitrogen oxides (NO_x) are formed mainly from N_2 and O_2 during combustion of fossil fuels at high temperatures in automobile

engines. NO_x stands for an indeterminate mixture of NO and NO_2. Nitrogen oxides cause the reddish-brown haze (**brown air**) in traffic-congested city air, which contributes to heart and lung problems and may be carcinogenic. Nitrogen oxides also contribute to acid rain because they combine with water droplets to produce nitric acid (HNO_3) and other acids.

Secondary Air Pollutants and their Effects

Photochemical smog : The classical example of secondary pollutant, photochemical smog is formed in traffic-congested metropolitan cities where warm conditions and intense solar radiation are present [Figs. 21.1(a) and (b)]. Photochemical smog is composed mainly of ozone (O_3), peroxyacetyl nitrate (PAN) and NO_x. It is often called brown air where solar radiation is intense. In areas or seasons of lesser solar radiation, smog formation is incomplete and the air is referred to as **grey air**. Automobile exhaust contains HC and NO and these play an important role in O_3 and PAN formation in urban environment. A simplified set of the photochemical reactions involved in smog formation is as follows :

Reaction occurring inside engine :

$$N_2 + O_2 \longrightarrow 2NO$$

Reactions occurring in atmosphere :

$$2NO + O_2 \longrightarrow 2NO_2$$

$$NO_2 \xrightarrow{\text{UV radiation}} NO + O$$

$$O + O_2 \longrightarrow O_3$$

$$NO + O_3 \longrightarrow NO_2 + O_2$$

$$HC + NO + O_2 \longrightarrow NO_2 + PAN$$

Smog ozone may damage plant as well as animal life. In plants, the main damage occurs in leaf. Ozone aggravates lung diseases in humans. Ozone, an effective oxidant, corrodes the heritage building surfaces and damages marble statues and other cultural assets. Several plant species are also very susceptible to PAN in smog. PAN damages chloroplasts (Fig. 21.2) and, thus, the photosynthetic

(a)

(b)

Fig. 21.1 *Photochemical smog can cause serious haze in a city : (a) clean condition, (b) smoggy condition*

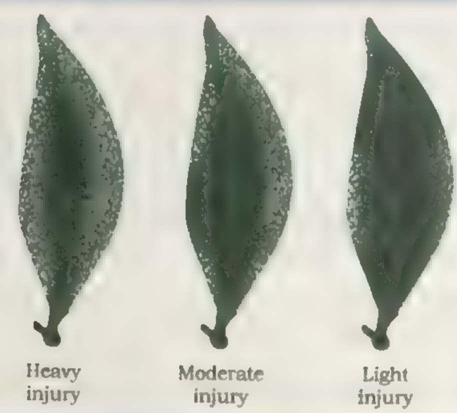


Fig. 21.2 *PAN-damaged milkweed leaves*

efficiency and growth of plants are reduced. It also inhibits electron transport system and interferes with enzyme systems that play important role in cellular metabolism. In humans, PAN causes acute irritation of eyes.

Acid rain : In a broad sense, acid rain refers to several ways in which acids from the atmosphere are deposited on the earth. Acid deposition includes wet and dry deposition (Fig. 21.3). **Wet deposition** refers to acidic water received through rain, fog, and snow. **Dry deposition** relates to the wind blown acidic gases and particles in the atmosphere, which settle down on the ground. About half of the acidity in the atmosphere is transferred to earth through dry deposition. Dry deposited gases and particles can also be washed from trees and other surfaces by rainfall.

Nitrogen oxides (NO_x), VOCs and SO_2 are produced during the combustion of coal (in industry) and petroleum (in automobile). Lightning in sky also produces NO_x naturally. These gases are highly reactive in air. They rapidly oxidise to acids (sulphuric or nitric), which quickly dissolve in water and are washed out to the ground as **acid rain**. Normally,

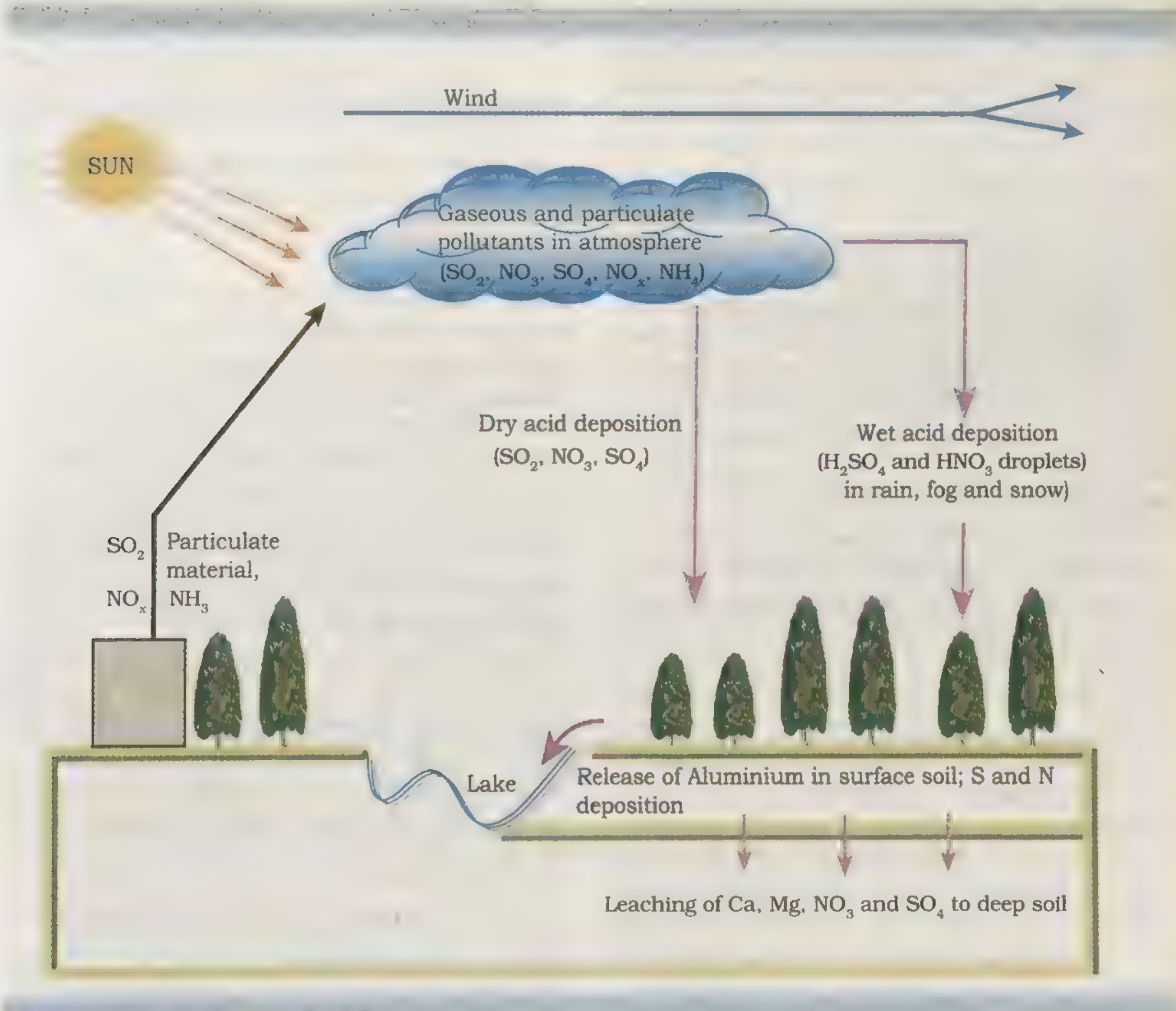


Fig. 21.3 *Dry and wet acid deposition or acid rain*

rainwater is slightly acidic (pH 5.6-6.5) because water and CO_2 combine in air to form a weak acid. The pH of acid rain is less than 5.6, and could be as low as 4 or below.

Acid rain damages building materials. Our heritage monuments (such as Taj Mahal at Agra) are threatened by the corrosive action of acid deposition. Acid rain adversely affects terrestrial and aquatic vegetation. Most planktons, molluscs and fry young fish cannot tolerate water having pH below 5.0. Low pH conditions also damage soil microbial community.

21.3 Control of Air Pollution

Important preventive strategies to control air pollution are : (i) suitable fuel selection (e.g., fuel with low sulphur content) and its efficient utilisation to reduce pollutant level in emission; (ii) modifications in industrial processes and/or equipments to reduce emissions; (iii) correct selection of manufacturing site and zoning for industrial set-up to disperse pollution sources. The most common methods of eliminating or reducing pollutants to an acceptable level include destroying the pollutant by thermal or catalytic combustion, changing the pollutant to a less toxic form, or collecting the pollutant by use of equipment to prevent its escape into the atmosphere.

Control of Particulate Matter

Principally, two devices remove particulate air pollutants, *viz.*, **arresters** (used ideally to separate particulate matters from contaminated air) and **scrubbers** (used to clean air for both dusts and gases by passing it through a dry or wet packing material). Particulate matter arresters may be of different kinds. **Cyclonic separators** and **trajectory separators** are commonly used to separate out particulate matters from industrial emissions with minimum moisture content. These separators work on the principle of dust separation by centrifugal force and are efficient for coarser dust particles. **Filters** are usually used to collect extremely fine particulate matters. Different types of filter materials are available to suit different quality and size of the particulate matters. However, **electrostatic precipitator** (ESP) is the most effective device to remove particulate pollutants (Fig. 21.4). ESP works on the principle of electrical charging of the dust particles and collecting it on a differently charged platform. Both dry and wet type scrubbers are also used for dust separation. However, scrubber is the least used device for separating particulate matters from the emissions, as this device is best suited for the removal of gaseous pollutants.

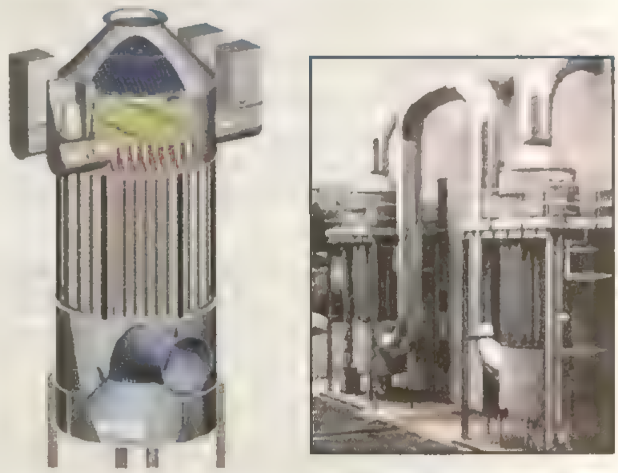


Fig. 21.4 *Electrostatic precipitator is an efficient device to eliminate particulate matters from the industrial emissions*

Control of Gaseous Pollutants

Combustion, absorption and adsorption techniques are used to control gaseous pollutants. In **combustion** process, oxidisable gaseous pollutants are completely burnt at a high temperature. Petro-chemical, fertiliser, paints and varnish industries use combustion control of gaseous pollutants. In **absorption** technique, gaseous pollutants are absorbed in suitable absorbent materials. **Adsorption** technique is applied to control toxic gases, vapours and inflammable compounds that could not be efficiently removed or transferred by the aforesaid techniques. Such air pollutants are adsorbed on large solid surfaces.

Control of Automobile Exhaust

Efficient engine (for example, multi-point fuel injection engine) can reduce the unburnt HC in auto-emissions. Catalytic converter filters in the vehicle can convert NO_x to nitrogen, reducing potential hazards of NO_x. Good quality automobile fuels can also drastically reduce the toxic contaminants in exhaust. Lead-free petrol can reduce the load of lead in the exhaust. Automobile engines operated with compressed natural gas (CNG) have significantly lowered toxic contaminants in exhaust.

21.4 Water Pollution : Sources, Types and Effects

Sources of Water Pollution

On the basis of their origin, the sources of water pollutants can be broadly categorised into : (i) **point sources**, where the effluent discharge occurs at a specific site; for example, sewage outlet of a municipal area or effluent outlet of a factory; and (ii) **non-point sources**, where inflow of pollutants occurs over a large area; for example, city storm water flow, agricultural runoff, etc. Point source pollution can be effectively checked with appropriate technology. Non-point source pollution is difficult to control and needs application of control measures on a large scale.

Water pollutants can be : (i) **biological** (pathogens, such as viruses, bacteria, protozoa, algae and helminths), (ii) **chemical** (organic chemicals like biocides, polychlorinated biphenyls or PCBs; inorganic chemicals, like phosphates, nitrates, fluoride, etc.; also heavy metals like As, Pb, Cd, Hg, etc.), and (iii) **physical** (hot water from industries, oil spills from oil carriers, etc.). These pollutants are generated by different sources and activities, which are briefly described below.

Municipal wastewater : Liquid wastes from domestic activities such as kitchen, toilet and other household wastewaters are, in most cases, discharged directly into a river or into a large water body nearby. Many rivers in India, including the river Ganga, Sabarmati, Karishna and Cauvery are polluted by indiscriminate discharge of wastewaters. The famous Dal Lake in Kashmir is also heavily polluted by domestic sewage. Domestic effluents mostly carry organic wastes, which are biodegradable. Excess input of nutrients occurs from detergent residues (e.g., phosphates) and organic remains (e.g., nitrates).

Industrial wastewater : Both small-scale and large industrial activities produce wastewaters contaminated by a variety of organic and inorganic pollutants. Almost all the rivers of India, at least in certain stretches, are heavily polluted by the discharge of industrial wastewater. Even the marine environment is not spared, and most of the coastal waters are threatened by pollution from the effluents of coastal prawn-culture farms and fish processing industries. Most components of industrial effluents are toxic to ecological systems even at low concentrations, and many are non-biodegradable.

Hot water is another notable pollutant from the industries. Many industries, including power plants and oil refineries, use water as coolant for the machinery. Release of hot wastewater, having 8 to10°C higher temperature than the intake water, causes thermal pollution in the water body.

Surface runoff from land : Pollutants in surface runoff (and storm water) vary according to the nature of land over which it flows. The runoff from agricultural land is contaminated with pesticides and residues of inorganic fertilisers. The runoff from urban areas mainly contains biodegradable organic pollutants. Industrial sites may contribute to varied types of pollutants, like heavy metals, acids and various inorganic compounds. All these pollutants in the runoff heavily contaminate our surface water and groundwater resources.

Oil spills : An oil spill is the accidental discharge of petroleum in oceans or estuaries. Capsized oil tankers, offshore oil mining and oil exploration operations and oil refineries mainly contribute to oil pollution of marine ecosystem. In addition to unpleasant aesthetic impact of oil-covered coastal region, the death

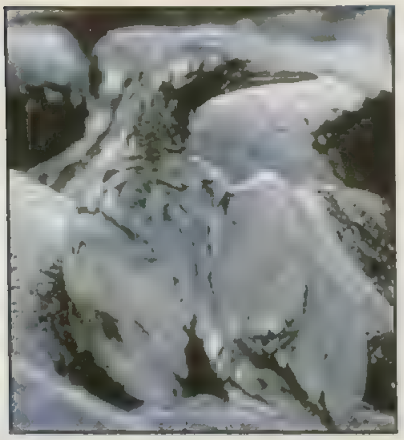


Fig. 21.5 *Oil spill damages the marine biodiversity; birds smeared with oil lose the capability to fly*

of plankton, fish and marine birds (Fig. 21.5) is a significant ecological effect of oil spills. Oil spills are also immensely harmful to coral reef and can drastically damage the marine and coastal biodiversity.

Effects of Water Pollution

Water pollutants adversely affect the physical, chemical and biological characteristics of the aquatic ecosystems and the quality of groundwater.

Effects on aquatic ecosystem : Organic and inorganic wastes decrease the dissolved O_2 (DO) content of water bodies. Water having DO content below 8.0 mg L^{-1} may be considered as contaminated. Heavily polluted waters have DO content below 4.0 mg L^{-1}. DO content of water is important for the survival of aquatic organisms. The surface turbulence, photosynthetic activity, O_2 consumption by organisms and decomposition of organic matter are the factors which determine the amount of DO present in water.

Higher amounts of organic waste increase the rates of decomposition and O_2 consumption, thereby causing a drop in DO content of water. The demand for O_2 is directly related to increasing input of organic wastes and is expressed as **biochemical oxygen demand** (BOD) of water. BOD is a measure of oxygen required by aerobic decomposers for the biochemical degradation of organic materials (i.e., biodegradable materials) in water. Higher the BOD, lower would be the DO. **Chemical oxygen demand** (COD) is another measure of pollution load in water. COD is the measure of oxygen equivalent of the requirement for oxidation of total organic matter (biodegradable + non-biodegradable) present in water.

Therefore, contamination of water bodies by pollutants will reduce DO content, and sensitive organisms, like plankton, molluscs, and fish etc. will be eliminated. Only a few tolerant species, like annelid worm *Tubifex* and some insect larvae may survive in highly polluted, low DO water, and they may be recognised as **indicator** species for polluted waters. Biocide residues, PCBs and heavy metals, such as Hg, Pb, Cd, Cu, As, etc. can directly eliminate different species of organisms.

Higher the temperature of water, lower is the rate of dissolution of O_2 in water. Hence, hot wastewaters discharged from industries, when added to water bodies, also lower its DO content.

Biological magnification : The phenomenon through which certain pollutants get accumulated in tissues in increasing concentrations along the food chain, is called **biological magnification** (Fig. 21.6). Such pollutants (e.g., DDT and PCB) are non-biodegradable, i.e., once they are absorbed by an organism, they cannot be metabolised and broken down or excreted out. These pollutants generally get accumulated in fat-containing tissues of the organism. The classic example of biological magnification is that of PCB (polychlorinated biphenyls), an industrial toxic waste which contaminated water in Great Lakes in USA during 1960s, leading to decline in fishes and birds. It was discovered that the PCB

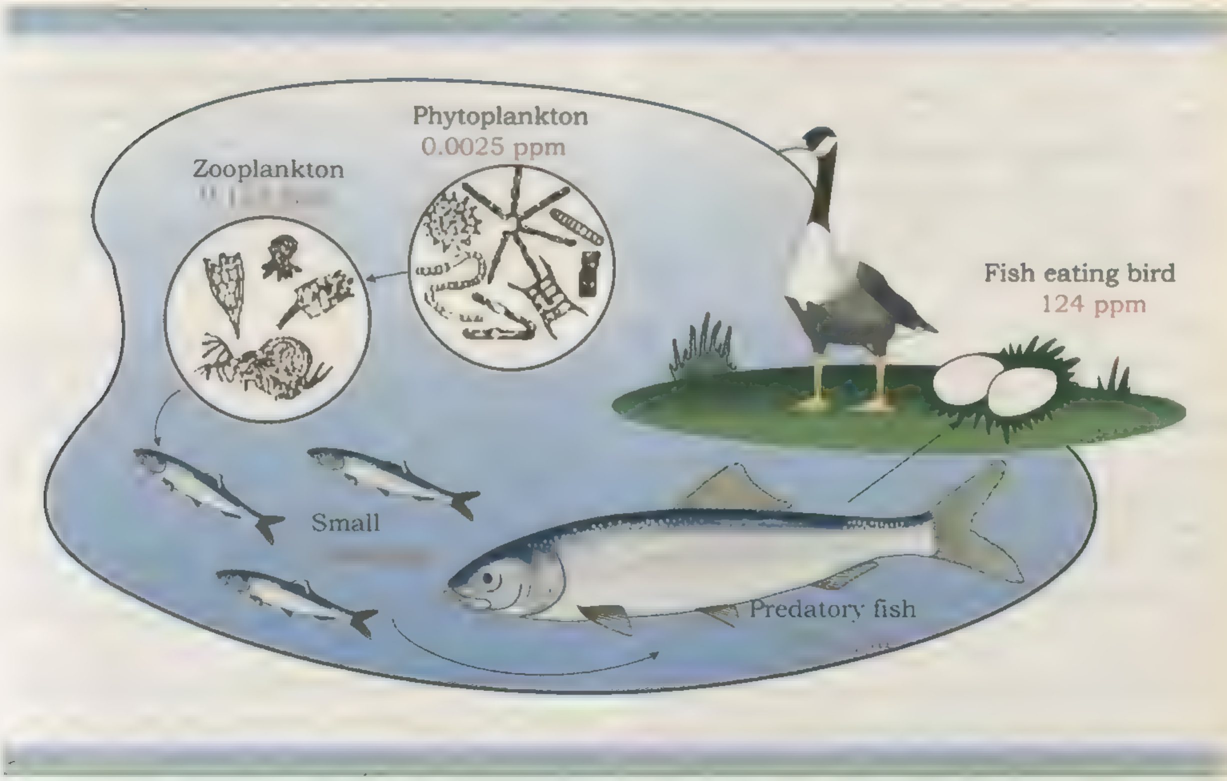


Fig. 21.6 *Process of biological magnification; PCB concentrations increase in organisms along the food chain*

concentration, which was 0.000002 ppm in water, increased along the food chain to as much as 4.83 ppm in fishes and 124 ppm in birds (Fig. 21.6). Many other persistent pesticides (e.g. DDT) show similar magnification. Pollutants like PCB and DDT are known to cause disruptions in animal reproduction.

Eutrophication : Besides inorganic nutrient input with the inflow of wastewater, decomposition of organic wastes too, increases the nutrient content of the water bodies. Availability of excess nutrients causes profuse growth of algae (**algal bloom**), especially the blue-green algae. Such algal blooms may totally cover the water surface, often release toxins in water, and sometimes cause deficiency of oxygen in the water. Thus, in bloom-infested water body the growth of other algae may be inhibited due to toxins, and aquatic animals (e.g., fish) may die due to toxicity or lack of oxygen. The process of nutrient enrichment of water, and consequent loss of species diversity is referred to as **eutrophication**.

Effects on human health : Domestic sewage contains pathogens like virus, bacteria, parasitic protozoa and worms. Contaminated water, therefore, can carry the germs of water-borne diseases like jaundice, cholera, typhoid, amoebiasis, etc. Such contamination may make the water unfit for drinking, bathing, and swimming, and even for irrigation.

Heavy metal contamination of water can cause serious health problems. Mercury poisoning (**Minamata disease**) due to consumption of fish captured from Hg-contaminated Minamata Bay in Japan, was detected in 1952. Mercury compounds in wastewater are converted by bacterial action into extremely toxic methyl mercury, which can cause numbness of limbs, lips and tongue,

deafness, blurring of vision, mental derangement. Cadmium pollution can cause **itai-itai** disease (ouch-ouch disease, a painful disease of bones and joints) and cancer of liver and lung.

Groundwater pollution : In India, at many places the groundwater is threatened with contamination due to seepage from industrial and municipal wastes and effluents, sewerage channels and agricultural runoff. For example, excess nitrate in drinking water is dangerous for human health and may be fatal for infants. It reacts with haemoglobin and forms non-functional **methaemoglobin** that impairs oxygen transport. This is called **methaemoglobinemia** or **blue-baby syndrome**. Excess fluoride in drinking water causes teeth deformity, hardened bones and stiff and painful joints (**skeletal fluorosis**). At many places in India, groundwater is contaminated with arsenic, mainly from naturally occurring arsenic in bedrocks. Overexploitation of groundwater may possibly initiate leaching of arsenic from soil and rock sources and contaminate groundwater. Chronic exposure to arsenic causes **black-foot disease**. Arsenic causes diarrhoea, peripheral neuritis, and hyperkeratosis, and also lung and skin cancers.

21.5 Improving Water Quality

The industrial and municipal wastewaters are treated in **Effluent Treatment Plant (ETP)** prior to disposal in water bodies. Generally, the following treatments are given in ETP :

(i) ***Primary treatment*** : This physical process involves the separation of large debris, followed by sedimentation in tanks or clarifiers.

(ii) ***Secondary treatment*** : This is a biological process and is carried out by microorganisms. In this treatment, the wastewater is pumped in shallow **stabilisation** or **oxidation** ponds, where the microbes oxidise its organic matter. The process results in release of CO_2 and formation of **sludge** or **biosolid**. The sludge is continuously aerated to further its oxidation. Algae grown in the upper lighted zone of the wastewater provide aeration by generating O_2.

(iii) ***Tertiary treatment*** : This physico-chemical process removes turbidity in wastewater caused by the presence of nutrients (nitrogen, phosphorus, etc.), dissolved organic matter, metals or pathogens (Fig. 21.7). This step involves chemical oxidation of wastewater by strong oxidising agents, such as chlorine

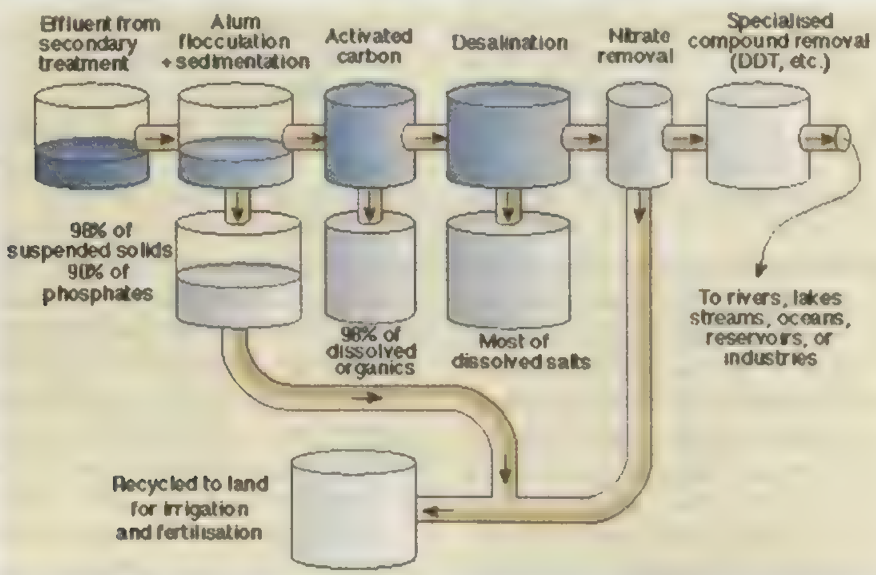


Fig. 21.7 *Diagrammatic representation of tertiary treatment in an Effluent Treatment Plant*

gas, perchlorate salts, ozone gas and UV radiation. After tertiary treatment, the wastewater can be discharged into natural waters or used for irrigation.

21.6 Soil Pollution

Soil pollution usually results from different human activities, like waste dumping, use of agrochemicals, mining operations and urbanisation.

Waste Dumps

Land gets polluted by dumping of industrial wastes, municipal wastes, and medical or hospital wastes. Industrial solid wastes and sludge are the major sources of soil pollution by toxic organic and inorganic chemical compounds and heavy metals. The fall out from industrial emissions, for example, the fly-ash emitted by thermal power plants, can pollute surrounding land. We must keep in mind that the particulates of the industrial emissions from the tall chimneys always come back to the earth's surface sooner or later. Radioactive wastes from nuclear testing laboratories and nuclear power plants and the radioactive fall out from nuclear explosions also contaminate the soil. Radioactive materials thrive in the soil for long periods because they usually have a long half-life. Strontium-90, for example, has a half-life of 28 years, and half-life of caesium-137 is 30 years.

Municipal Wastes

Municipal wastes mainly include domestic and kitchen wastes, market wastes, hospital wastes, livestock and poultry wastes, slaughterhouse wastes, waste metals, and glass and ceramic wastes, etc. Non-biodegradable materials like used polyethylene carry-bags, waste plastic sheets, pet-bottles, etc. persist in soil for long periods. Hospital wastes contain organic materials, chemicals, metal needles, plastic and glass bottles, vials, etc. Dumping of domestic sewage and hospital organic wastes contaminate the environment with a variety of pathogens that can seriously affect human health.

Agrochemicals

Pesticides and weedicides are being increasingly applied to control pests and weeds in agricultural systems. Excess inorganic fertilisers and biocide residues are contaminating the soil as well as surface and groundwater resources. Inorganic nutrients, like phosphate and nitrate are washed out to aquatic ecosystems and accelerate eutrophication there. Nitrate can also pollute drinking water. Inorganic fertilisers and pesticide residues change the chemical properties of soil and can adversely affect soil organisms.

Mining Operations

Opencast mining (a process where the surface of the earth is dug open to bring out the underground mineral deposits) completely devastates the topsoil and contaminates the area with toxic metals and chemicals.

Control of Soil Pollution

Control measures for soil pollution and land degradation involve safer land use, planned urbanisation, controlled developmental activities, safe disposal and management of solid wastes from industries and human habitations. Management of solid wastes involves : (i) collection and categorisation of wastes, (ii) recovery of resources like scrap metals, plastics, etc., for recycling and reuse, and (iii) safe disposal with minimum environmental hazards.

Sewage sludge and industrial solid wastes are used as landfills. Toxic chemicals and hazardous metal-containing wastes are used as bedding material for road construction. Fly-ash is also used for similar purposes. Fly-ash bricks are also being used for building constructions. Other notable methods to get rid of the solid wastes are **incineration** (burning in presence of oxygen) and **pyrolysis** (combustion in the absence of oxygen). Municipal solid wastes containing biodegradable organic wastes, can be transformed into organic manure for agriculture.

21.7 Noise Pollution

Sources and Effects

Noise pollution can be defined as the loud disturbing sound dumped into the ambient atmosphere without regard to the adverse

effects it may have. Sound travels in pressure waves and affects our eardrums. The intensity of a sound wave is the average rate per unit area at which energy is transferred by the wave onto the surface (expressed as W m^{-2}). The **sound level** is the logarithm of ratio of the ambient intensity to the reference intensity (usually considered 10^{-12} W m^{-2}). The unit of sound level is ***decibel*** (dB), a name that was chosen to recognise the work of Alexander Graham Bell. When the ambient sound intensity is equal to the reference intensity, the sound or noise level is 0 dB. Noise level can range from 0 to more than 120 dB, at which point physical discomfort starts. In view of the logarithmic nature of scale, 10, 20 and 100 decibels represent 10 times, 100 times and 10^{10} times the threshold intensity, respectively.

Man-made noise originates from industrial machines, transport vehicles, sound amplifiers, cracker blasting, industrial and mining site detonation, etc. Jet aircraft landing and take-off create a lot of noise pollution to the inhabitants near the busy airports. Noise has many ill effects on human physiological functions. Noise seriously affects heartbeat, peripheral circulation, and breathing pattern. Persistent noisy environment can cause annoyance, irritability, headache, and sleeplessness, and may seriously affect productive performance of humans.

The Central Pollution Control Board has recommended zone-wise ambient noise levels as given in Table 21.1.

Control of Noise Pollution

Soundproof insulating jackets or filters are used to reduce noise from machines. Industrial workers and runway traffic control personnel may use earmuffs to protect themselves from unwanted noise exposure. Acoustic zoning to prevent noise propagation may also be helpful. A 'silent zone' around 100 meters of hospitals or schools can give comfort to ailing patients or help students to concentrate in studies. Forests and dense hedge of plants can effectively act as noise barrier. Sound must be considered as a potentially harmful pollutant around us and should be treated with no less importance than the other pollutants of our environment. Efforts must be made to increase awareness among people about the perils of noise in our surroundings.

21.8 Environmental Laws for Controlling Pollution

Important legislations directed at the protection of environment in India are listed below :

The Environment (Protection) Act, 1986

This Act clearly brings the protection of air, water and soil quality, and the control of environmental pollutants, including noise, under its purview.

The Insecticide Act, 1968

This Act deals with the regulation of import, manufacture, sale, transport, distribution and use of insecticides with a view to prevent risk to human health and other organisms.

The Water (Prevention and Control of Pollution) Act, 1974

This Act deals with the preservation of water quality and the control of water pollution with a concern for the detrimental effects of water pollutants on human health and also on the biological world.

The Air (Prevention and Control of Pollution) Act, 1981

The Act deals with the preservation of air quality and the control of air pollution with a concern for the detrimental effects of air

Table 21.1 : Zone-wise Permissible Ambient Noise Levels

Zones	Day (6.00-21.00 hr)	Night (21.00-6.00 hr)
Industry	75 dB	70 dB
Commercial	65 dB	55 dB
Residential	55 dB	45 dB
Silent zone	50 dB	40 dB

pollutants on human health and also on the biological world. In 1987, important amendments to the Air Act 1981 were made and noise was recognised as an air pollutant.

21.9 Global Environmental Change

The human activities that are transforming the biosphere include land use changes, industrial development, energy production from fossil fuels and urbanisation. The conversion of a forest to a grazing land or a cropland through deforestation causes loss of carbon stored in soil and vegetation to the atmosphere, and affects the global carbon cycle. Biomass burning associated with agricultural practices also releases CO_2 into the atmosphere. In recent times, due to domestic and industrial coal burning, huge amount of CO_2 is being pumped into the atmosphere. Similarly, the concentrations of gases like methane (CH_4), nitrous oxide (N_2O) and chlorofluorocarbons (CFCs) are increasing in the lower atmosphere. These gases (CO_2, CH_4, N_2O and CFCs) are **radiatively active gases** (also called **greenhouse gases**) because they can absorb long wave infrared radiation. The increased amounts of greenhouse gases in the atmosphere are affecting the global climate and this phenomenon is now recognised as **Global Climatic Change**.

Greenhouse Gases and Global Warming

The atmospheric cover around the earth acts like a window glass pane. It allows most of the solar radiation to enter right up to the earth's surface, but does not allow a substantial amount of the long-wave radiation emitted by the earth to escape in space. The outgoing long-wave infrared radiation is absorbed by the greenhouse gases normally present in the atmosphere. The atmosphere radiates part of this energy back to the earth. This downward flux of radiation, called **greenhouse flux**, keeps the earth warm. Thus, the atmospheric greenhouse gases forming a blanket over the earth, control the escape of heat from the earth's surface to outer space so as to keep it warm and hospitable (Fig. 21.8). This phenomenon is referred to as **greenhouse effect**. The name

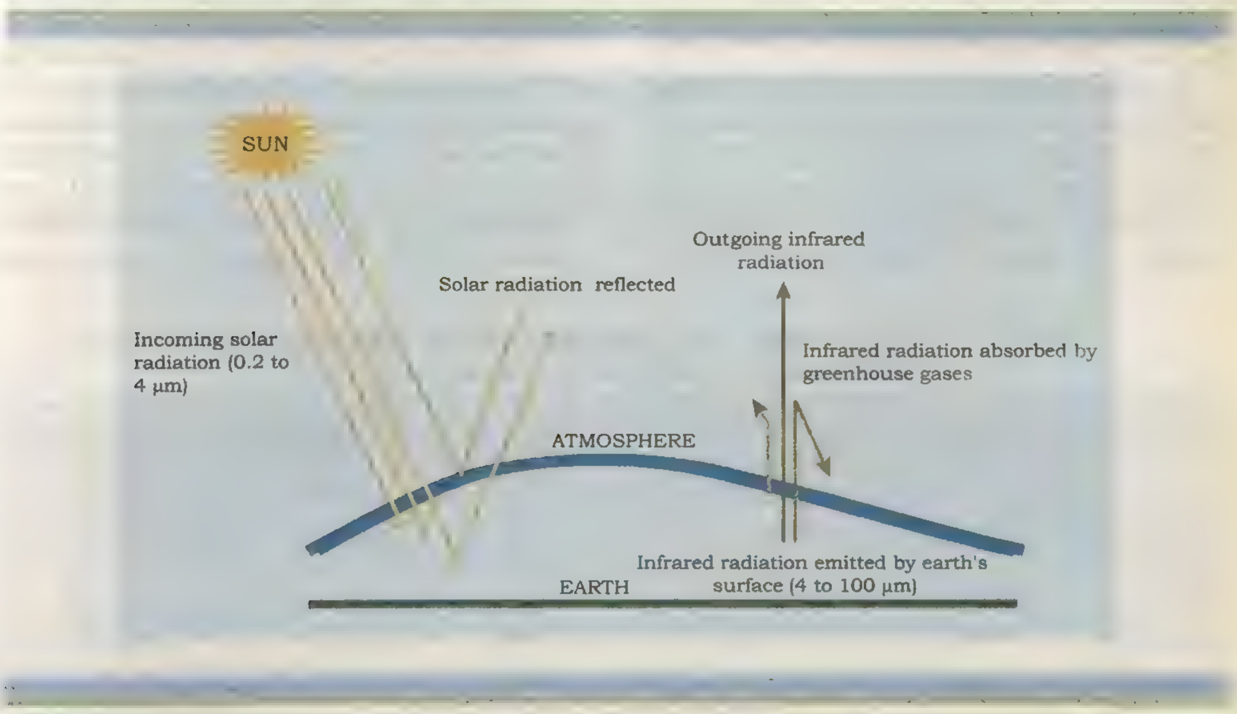


Fig. 21.8 *The greenhouse effect : the atmosphere is transparent to the incoming short-wave radiations; it is translucent to the long-wave infrared radiations which are absorbed by the greenhouse gases to make the earth warm*

is derived from the fact that inside a glass-enclosed greenhouse, temperature is warmer than outside. Such greenhouses are used for growing plants that require higher temperatures for growth. The mean annual temperature of the earth is about 15°C; however, in the absence of greenhouse gases in the atmosphere, the earth's mean temperature would drop sharply to about –20°C. This capacity of the atmosphere to keep the earth warm depends upon the concentration of greenhouse gases. The excessive increase in concentrations of these gases in the atmosphere would retain more and more of the infrared radiation, resulting in **enhanced greenhouse effect**. The consequent increase in the global mean temperature is referred to as **global warming**. The Intergovernmental Panel on Climate Change (IPCC) periodically makes an assessment of the atmospheric abundance of greenhouse gases and its possible impact on climate and related issues. Much of what you will read in this section is based on IPCC assessment reports.

The trends in the increase in concentrations of greenhouse gases since pre-industrial times are briefly described below :

Carbon dioxide : CO_2 is the most abundant greenhouse gas in the atmosphere. The level of CO_2 in the atmosphere has increased from the pre-industrial level of 280 ppm to about 368 ppm in 2000 (Table 21.2). This has been largely the result of fossil fuel burning, deforestation and change in land use.

Methane : Methane concentration in atmosphere has more than doubled (1750 ppb) than its concentration during the pre-industrial times (Table 21.2). Methane is largely a product of incomplete decomposition and is produced by a group of bacteria called **methanogens**, under anaerobic conditions. The major sources of methane include : freshwater wetlands, enteric fermentation in cattle, and flooded rice fields. Biomass burning also produces methane.

Chlorofluorocarbons (CFCs) : CFCs are non-toxic and non-flammable, highly stable and synthetic gaseous compounds of carbon and halogens. Although these compounds were synthesised during the 20^{th} century, their concentration in the atmosphere has increased. For example, the concentration of CFC-11 and HFC-23 in the air is about 282 ppt (Table 21.2). Major sources of CFCs are leaking air conditioners, refrigeration units and evaporation of industrial solvents, and production of plastic foams and propellants in aerosol spray cans. The CFCs persist for 45 to 260 years or more in the atmosphere.

Nitrous Oxide (N_2O) : The concentration of nitrous oxide in the atmosphere has increased from about 270 ppb in pre-industrial time to about 316 ppb in recent times (Table 21.2). The main sources of N_2O are agriculture, biomass burning and industrial processes. N_2O is produced during nylon

Table 21.2 : The Increase in the Concentrations of Greenhouse Gases in the Atmosphere as Affected by Human Activities

Greenhouse gases	Pre-industrial Concentration ~ 1750 AD	Concentration in 2000 AD	Increase since ~1750 AD %	Atmospheric life-time (years)
Carbon dioxide (CO_2)	280 ppm	368 ppm	31	5-200
Methane (CH_4)	700 ppb	1750 ppb	151	12
Nitrous oxide (N_2O)	270 ppb	316 ppb	17	114
Chlorofluorocarbons (CFC-11) + Hydroflurocarbons (HFC-23)	0	282 ppt		45-260

ppm – parts per million; ppb – parts per billion; ppt – parts per trillion.

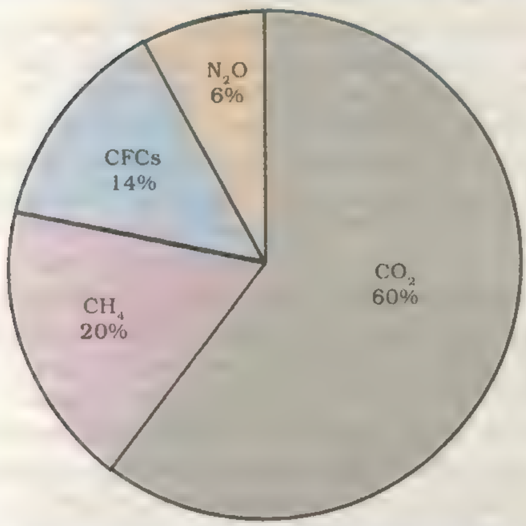


Fig. 21.9 *The relative contribution of different greenhouse gases to global warming*

production, burning of nitrogen-rich fuels, livestock waste, breakdown of nitrogen-rich fertilisers in soil and nitrate-contaminated ground water.

It is estimated that CO_2 contributes about 60 per cent of the total global warming (Fig. 21.9). The share of CH_4 and CFCs is 20 per cent and 14 per cent, respectively. A smaller contribution to global warming is made by N_2O (6 per cent).

The increasing abundance of greenhouse gases in the atmosphere has the following possible effects :

(i) CO_2 fertilisation
(ii) Global warming
(iii) Depletion of ozone layer in the stratosphere.

CO_2 Fertilisation Effect on Plants

The measurements made at Mauna Loa Observatory in USA have shown that atmospheric CO_2 concentration has been rapidly rising since 1959 (Fig. 21.10). If this rising trend continues, it is expected that the atmospheric CO_2 concentration shall increase to a level between 540 and 970 ppm by the end of the 21st century.

With a doubling of the atmospheric CO_2 concentration, the growth of many plants, particularly the C_3 species, under favourable conditions of water, nutrients, light and temperature, could increase by about 30 per cent on average, in the short-term (i.e., up to a few years). The response of plants to elevated concentrations of CO_2 is known as the **Carbon dioxide fertilisation effect**. Due to increased CO_2 concentration, the rate of photosynthesis will increase and the stomatal conductance will

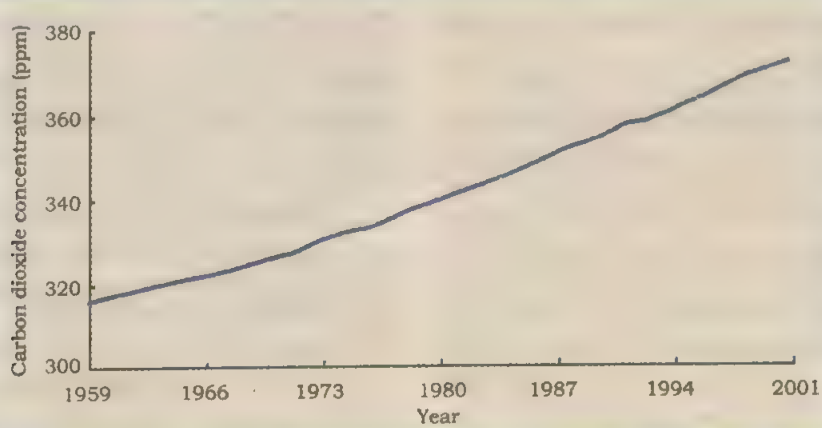


Fig. 21.10 *The increase in mean carbon dioxide concentration in the atmosphere from 1959 to 2001 (Based on a data from Mauna Loa Observatory, USA)*

decrease (due to partial closure of stomata). Thus, the transpiration rate may be reduced and consequently, water-use efficiency will increase. This may allow many species to grow successfully in regions of water scarcity. Under higher atmospheric CO_2 conditions, plants shall allocate a greater proportion of photosynthate to roots. Greater root production is expected to enhance mycorrhizal development and fixation of N_2 in root nodules, thereby enabling the plants to grow in nutrient-poor soils. However, under natural conditions, the beneficial effects of increased CO_2 may not be actually realised because of negative effects of global warming.

Possible Effects of Global Warming

The predicted global warming in near future has the potential to affect the weather and climate, sea level, and the distribution and phenology of organisms, food production and fishery resources in the oceans. Let us study some of these effects.

Effects on weather and climate : The global mean temperature has increased by approximately 0.6°C in the 20th century. The average temperature of the earth may increase by 1.4 to 5.8°C by the year 2100 from the 1990 level. Temperature changes are expected to be most marked in regions of middle and higher latitudes. Warming of atmosphere will considerably increase its moisture carrying capacity. While the troposphere warms up, the stratosphere will cool down. This would cause widespread changes in precipitation patterns due to changed pattern of air-mass movements. Precipitation is expected to increase at higher latitudes in both summer and winter and in southern and eastern Asia in summer. Winter precipitation may decrease at lower latitudes. Besides, the frequency of extreme events (e.g., droughts, floods, etc.) is expected to increase substantially. The climate change will increase threats to human health, particularly in tropical and subtropical countries, due to change in ranges of disease vectors, water-borne pathogens, etc.

Sea level change : Sea level has been raised by 1 to 2 mm per year during the 20th century. It is predicted that by the year 2100, the global mean sea level can increase up to 0.88 m over the 1990 level. The global warming may contribute to sea level rise due to the thermal expansion of ocean as it warms, and melting of glaciers and Greenland ice sheets. A rise of even half a meter in sea level would profoundly affect human population, one-third of which lives within 60 km of a coastline. Many of the world's important cities and coastal areas will come under the threat of flood. Several low-lying islands may be submerged. Inundation of coastal salt marshes and estuaries may deprive many important birds and fish their breeding grounds, forcing their extinction. Thus, sea-level rise is projected to have negative impacts on human settlements, tourism, freshwater supplies, fisheries, exposed infrastructure, agricultural lands, and wetlands.

Effects on range of species distribution : You may recall from chapter 16 that each plant or animal species occurs within a specific range of temperature. The global warming is likely to shift the temperature ranges and, therefore, would affect altitudinal and latitudinal distribution pattern of organisms. With increasing global warming many species are expected to shift slowly poleward, or toward high elevations in mountain areas. For example, with a global temperature rise by 2 to 5°C during the 21st century, the temperate region vegetation may extend 250-600 km poleward. Since trees are sensitive to temperature stress, a rapid rise in temperature may cause large scale death of trees and their replacement by scrub vegetation. Many species may not be able to migrate fast enough to track temperature changes and may disappear.

Food production : Increased temperature will cause eruption of plant diseases and pests, explosive growth of weeds and increased basal rate of respiration of plants. A combination of all these factors will decrease the crop production. Small temperature increase may slightly enhance crop productivity in temperate regions, but larger temperature changes will reduce crop productivity there. In all tropical and sub-tropical regions, even a small temperature rise will have detrimental effect on

crop productivity. Rice yield alone, in south-east Asia, will reduce by 5 per cent for each 1°C increase in temperature. Despite beneficial CO_2 fertilisation effect, the overall world crop productivity will, in all probabilities, decline considerably due to projected global warming. This will have alarming consequences on world food supply.

Approaches to Deal with Global Warming

Some of the strategies that could reduce the warming by global stabilising atmospheric concentrations of greenhouse gases include :

(i) Reducing the greenhouse gas emissions by limiting the use of fossil fuels, and by developing alternative renewable sources of energy (e.g., wind energy, solar energy, etc.).

(ii) Increasing the vegetation cover, particularly the forests, for photosynthetic utilisation of CO_2.

(iii) Minimizing the use of nitrogen fertilisers in agriculture for reducing N_2O emissions.

(iv) Developing substitutes for chlorofluorocarbons.

Apart from the above mitigation strategies, adaptations to address localised impacts of climate change will be necessary.

Stratospheric Ozone Depletion

Stratospheric O_3 layer : In the stratosphere, UV-radiation from the sun causes photodissociation of ozone into O_2 and O. But O_2 and O quickly recombine to form O_3. This ozone dynamics dissipates the energy of UV as heat. An equilibrium is established between generation and destruction of O_3, leading to a steady state concentration of ozone layer in the stratosphere between 20 and 26 km above the sea level. The thickness of the vertical column of stratospheric O_3 layer, condensed to standard temperature and pressure, averages 0.29 cm above the equator and may exceed 0.40 cm above the poles at the end of the winter season. This layer acts as the **ozone shield** protecting the earth biota from harmful effects of strong UV-radiation. Absorption of UV-radiation by ozone layer increases exponentially with its thickness. Therefore, maximum amount of UV-radiation passing through the atmosphere reaches the earth surface in the tropics (i.e., near the equator), and this amount decreases towards the poles. The concentration of O_3 in the stratosphere changes with seasons, the concentration being highest during the period February-April (spring season) and lowest during July-October (fall season).

Ozone hole : During the period 1956-1970, the spring-time O_3 layer thickness above Antarctica varied from 280 to 325 Dobson Unit (1 DU = 1 ppb). The thickness was sharply reduced to 225 DU in 1979 and to 136 DU in 1985. Later, the O_3 layer thickness continued to decline to about 94 DU in 1994. The decline in spring-time ozone layer thickness is termed **Ozone hole**. The ozone hole was first discovered in 1985 over Antarctica. The existence of ozone hole was also confirmed above Arctic in 1990. The global-average total column ozone amount for the period 1997-2001 was about 3 per cent below the pre-1980 average values.

CFCs, CH_4 and N_2O escape into the stratosphere and cause destruction of O_3 there (Fig. 21.11). Most damaging is the effect of CFCs, which produce "active chlorine" (Cl and ClO radicals) in the presence of UV-radiation. These radicals catalytically destroy ozone, converting it into oxygen. CH_4 and N_2O also cause ozone destruction through a complicated series of reactions. For making these discoveries related to O_3 destruction, Sherwood Rowland and Mario Molina, along with Paul Crutzen, were honoured with Nobel Prize for Chemistry in 1995.

Effect of ozone depletion : The thinning of the ozone layer results in an increase in the UV-B radiation reaching the earth surface. A 5 per cent loss of ozone results in a 10 per cent increase in UV-B radiation. In humans, the increased UV-radiation increases the incidence of cataract, and skin cancer (including melanoma) and diminishes the functioning of immune system. Elevated levels of UV-B radiation affect photosynthesis, as well as damage nucleic acids in living organisms. UV-B radiation inhibits photosynthesis in most phytoplankton as it penetrates through the clear open ocean waters. This, in turn, can affect the whole food chain of organisms that depend on phytoplankton.

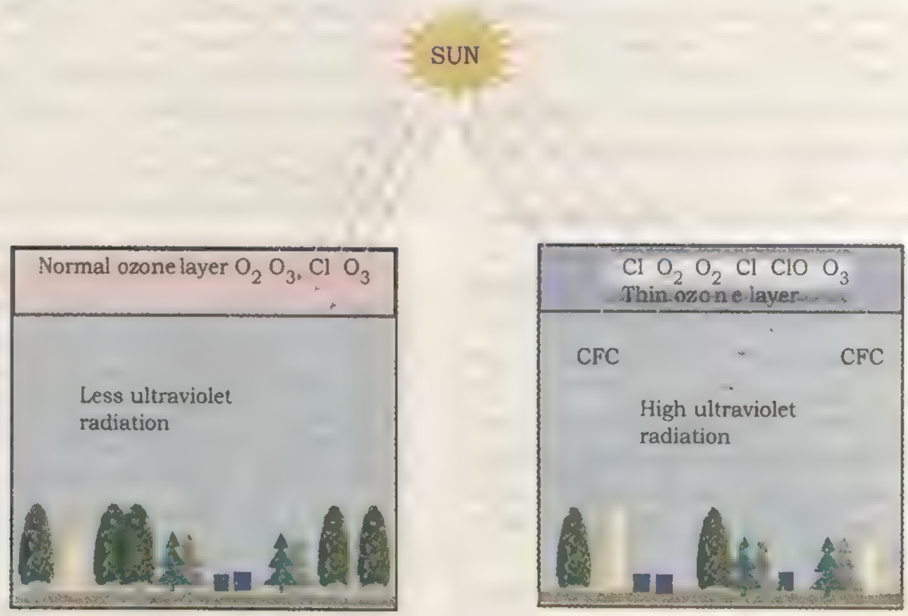


Fig. 21.11 *The effect of man-made chemicals on the ozone layer in the stratosphere : Left : less ozone reaches the earth's surface due to intact ozone layer; Right : high amount of UV-radiation reaches the earth's surface (ozone hole) due to thinning of ozone layer by the ozone-depleting substances*

21.10 International Initiative for Mitigating Global Change

The long-term challenge of stabilising the atmospheric concentrations of greenhouse gases requires that global emissions be significantly lowered than what they are today. In 1987, 27 industrialised countries signed the **Montreal Protocol**, a landmark international agreement to protect the stratospheric ozone by agreeing to limit the production and use of ozone-depleting substances, phasing out of ozone-depleting substances and helping the developing countries to implement use of alternatives to CFCs. To-date, more than 175 countries have signed the Montreal Protocol. The United Nations Conference on Environment and Development (UNCED, **Earth Summit**), held at Rio de Janeiro, Brazil in 1992, established the principles for reducing greenhouse gas emission. The **Kyoto Protocol**, approved by a follow-up conference held in Kyoto, Japan, during December 1997, has specified the commitments of different countries to mitigate climate change. This protocol requires countries to take appropriate measures to reduce their overall greenhouse gas emissions to a level at least 5 per cent below the 1990 level by the commitment period 2008-2012.

SUMMARY

Pollution may be defined as an undesirable change in physical, chemical or biological characteristics of our air, water and land, resulting in air pollution, water pollution and soil pollution. There are five types of primary air pollutants: particulate matter, carbon monoxide (CO), hydrocarbons (HCs), sulphur dioxide (SO_2), and nitrogen oxides (NO_x). Secondary air pollutants are formed during chemical reactions between primary air pollutants and other atmospheric constituents, such as water vapour. Different control measures are being adopted to combat pollution from gaseous and particulate matters in industrial emissions or automobile exhausts.

Types of water pollutants can be biological (pathogens like viruses, bacteria, protozoa, blue-green algae and helminths), chemical (organic chemicals like biocides, polychlorinated biphenyls (PCBs), and inorganic chemicals like phosphates, nitrates, fluoride etc., and also heavy metals like As, Pb, Cd, Hg, etc.) and physical (hot water from industries, oil spills from oil carriers, etc.). Water pollutants adversely affect the physical, chemical and biological health of the aquatic ecosystems, quality of groundwater and human health. Most of the industrial and municipal wastewaters are treated in Effluent Treatment Plants (ETPs) for safe disposal.

Soil pollution and land degradation usually result from different human activities, like waste dumping, agricultural practices, deforestation, mining operations and urbanisation. Control measures for soil pollution include safe disposal and management of solid wastes from industries and human habitations. Man-made noise that originates from industry, transport, sound amplifiers, can also pollute our environment. Several laws have been enacted in India for the control of air, water, soil and noise pollution.

Major issues of global environmental change are global warming and stratospheric ozone depletion. Naturally occurring greenhouse gases like carbon dioxide, methane and N_2O, in the atmosphere absorb long-wave radiations and help maintain the average temperature of earth around 15°C. The increase in concentrations of greenhouse gases is causing enhanced greenhouse effect, increased global temperature, sea level rise, and change in rainfall pattern, etc.

Stratospheric ozone plays a vital role by protecting the living organisms from the harmful effects of ultraviolet radiations. Ozone hole refers to the thinning of stratospheric ozone layer during spring. Ozone hole was discovered over Antarctica, but it also occurs over the Arctic region. The man-made chemicals like CFCs are the major cause of ozone depletion.

EXERCISES

1. Define pollution. Compare the biodegradable and non-biodegradable pollutants.
2. Explain the phenomenon of biological magnification.
3. What do you understand by fixed and mobile sources of air pollution?
4. Distinguish between the primary and secondary air pollutants.

5. What is particulate matter? How do particulate matters harm human health?
6. What is photochemical smog? How does smog affect the biological world?
7. What is acid rain? What are its effects on plants?
8. What measures do you suggest to control pollution from automobile exhausts?
9. Distinguish between point and non-point sources of water pollution.
10. Why are industrial effluents more difficult to manage than municipal sewage? Name a disease that is caused by heavy metal contamination.
11. How can pollution by domestic sewage be controlled?
12. Describe the ways by which soil gets polluted.
13. What are the control measures used for controlling soil pollution.
14. What is noise? Describe briefly the effects of noise on human health.
15. Which one of the following is not a greenhouse gas : CO_2, CH_4, O_2, CFCs.
16. Discuss the causes and effects of global warming.
17. State the consequences of stratospheric ozone depletion.
18. The ultraviolet radiations in the stratosphere are absorbed by :
    (a) Oxygen
    (b) Ozone
    (c) Sulphur dioxide
    (d) Argon.
19. Explain the following :
    (i) Greenhouse effect
    (ii) CO_2 fertilisation effect
    (iii) Ozone hole.
20. What is meant by the ozone shield? How do the CFCs and ozone depleting substances affect ozone shield?
21. What are the effects of ultraviolet radiations on humans?
22. What is the environmental significance of the increasing Antarctica ozone hole?

UNIT TEN
BIOLOGY IN HUMAN WELFARE

Human society has transformed from the primitive hunter-gatherer to the present-day technology-dependent society. Initially, humans domesticated certain plants and animals to fulfil their needs. Much later, they began efforts to improve the genetic make up of these species to make them more useful. More recently, systematic exploitation of micro-organisms as well as animal and plant cells, including their components, has assumed increasing significance, particularly when it is coupled with recombinant DNA technology. These developments have generated unique products and services and hold seemingly unlimited promise. But, they also have opened unsavoury prospects, like biowar, and biopiracy. Technological advances have supported continued growth in human population, which has been growing exponentially during the past 300 years or so. An enlarging human population pressurises the environment and the natural resources. But humans themselves serve as a unique resource for the development of a nation, provided they have sound physical and psychological health. Adolescence is a stormy phase of human life when individuals face physical as well as psychological challenges, and are relatively more prone to drug abuse. Educational and other programmes should, therefore, equip young people to tackle these challenges effectively. Physical health of humans is possibly the most intensively cared for aspect of human life. There has been a rapid advancement in the diagnostic tools, and in surgical and other approaches, including gene therapy, to manage and treat human ailments. In this context, vaccination is unique in that it uses either the pathogen itself (either dead or weakened), or an antigen derived from it to generate resistance to the disease in question. This is a brilliant exploitation of the 'memory' property of acquired immunity. This unit is devoted to a survey of the various ways in which the knowledge of biology is used for promoting human welfare.

Norman Ernest Borlaug

(1914-)

Norman Ernst Borlaug, born in March 1914 in an Iowa farm, became a towering figure in the green revolution of 1960's. Borlaug, during the last three and half decades collaborated and shared his experiences on problems of wheat improvement with his fellow scientists from Mexico and other countries. He also encouraged and collaborated with scientists from India, Pakistan and other countries in adapting new varieties of wheat. He was a big motivation force for convincing the scientists and the Governments for introduction of new wheat varieties. He is a goal-oriented scientist with pragmatic approach with constant search for more effective methods.

After completing his college education, Borlaug studied forestry and pursued his further studies in plant pathology for masters and doctorate degree. He was also actively involved in research on industrial and agricultural bactericides, fungicides and preservatives. Later, he worked as geneticist and plant pathologist. He was also made responsible for directing the research on wheat in the collaborative programme of Mexican Government and Rockfeller Foundation. His responsibilities included the research in diverse fields of his interest. In span of two decades he achieved a spectacular success in developing a high yielding, short-strawed and disease-resistant wheat.

He also worked to use this scientific research for humanitarian purpose. He saw to it that new cereal strains are used extensively for production to feed the hungry people of the world. This, according to him, is a "temporary success in man's war against hunger and deprivation". He considers it a breathing space in which to deal with "population monster" and the subsequent environment and social ills, often resulting in conflicts between humans and nations. Noble peace prize was conferred on him in 1978 for his contribution to food security, environment and reduction of social ills and conflicts. He also received acclaimation from several universities and research institutions in the form of fellowships and awards of excellence.

Dr. Borlaug also became the Director of Wheat Improvement Programme, which enabled him to achieve his another objective of training young scientists in research and production methodology. This Center has succeeded in providing training to more than 2000 young students from several countries. At present, Borlaug is involved in experimentation with triticale, a man-made grain developed through a cross between wheat and rye.

Chapter 22

Human Population and Health

In the earlier Chapters, you have learnt about the concept of ecosystem and the delicate balance between the living and the non-living worlds around us. By now, you also have an idea of our natural resources and how human activities are polluting and decimating these resources. The ever-growing human population is overexploiting natural ecosystems to satisfy the variety of needs, which reflect the increasingly energy-intensive lifestyle. This overexploitation is disturbing the natural balance.

Modern humans (*Homo sapiens sapiens*) appeared around 50,000 years ago from the archaic *Homo sapiens* that existed between 100,000 and 200,000 years ago. Initially, the human population was small. Therefore, human interference with nature was minimal. Human population reached the one billion mark around 1850. It increased to 2 billion by 1930, and reached 6 billion by 2000. In this chapter, we shall examine the growth of human population, its impact on environment, and the factors that control this growth.

22.1 Exponential Growth and Human Population Explosion

In 1700 A.D., human population was around 0.6 billion. At the beginning of the twentieth century, it increased to 1.6 billion, and by the end of the century, the human population was 6.1 billion. This dramatic increase in population size, i.e., number of individuals over a relatively short period is called **population explosion**. In the 150 years from 1700 A.D., human population doubled from 0.6 billion to 1.2 billion. In contrast, it increased five-fold during the next 150 years.

There is a limit to the maximum population size that can be supported with a given space and resource base. The maximum population size that can be supported by the environment is called the **maximum carrying capacity**. For the purpose of this chapter, it is useful to consider environment as having the following three major components : (i) The first component consists of productive systems, such as croplands, orchards, etc. and provides food and fibre; (ii) The second component comprises protective systems, such as climax forests, oceans, etc. It buffers air and water cycles, moderates extremes in temperature, etc.; (iii) The final component has waste assimilative systems, such as water ways, wetlands, etc. that assimilate the wastes produced by human activities.

The first two of these components constitute the **life-supportive capacity**, and the third makes up the **waste-assimilative capacity** of the environment. The maximum carrying capacity of the environment depends on the above two capacities. It is understandable that the population size should not exceed the maximum carrying capacity, and the utilisation of resources should be such that lasting damage to the environment does not occur.

The carrying capacity of the human environment has been increased many times by clever applications of science and technology, particularly to the productive systems of the environment. As a result,

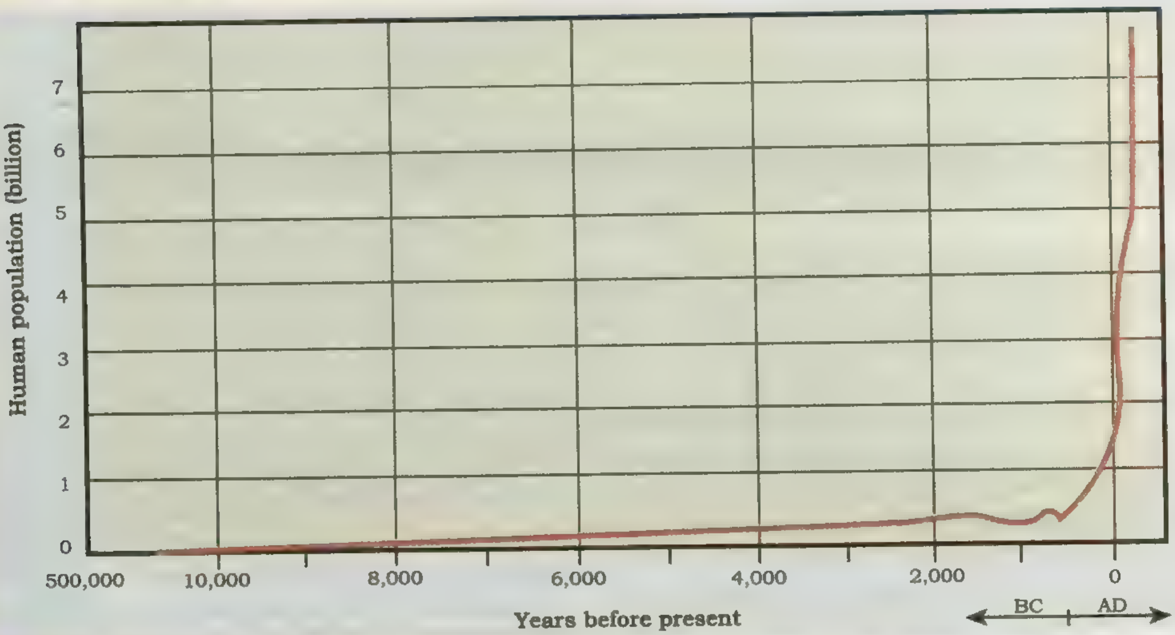


Fig. 22.1 *Growth of human population through ages and shows the recent exponential growth*

human population has been able to maintain exponential growth during the past 100 years (Fig. 22.1). When the population increase is nearly a fixed proportion of its own size during

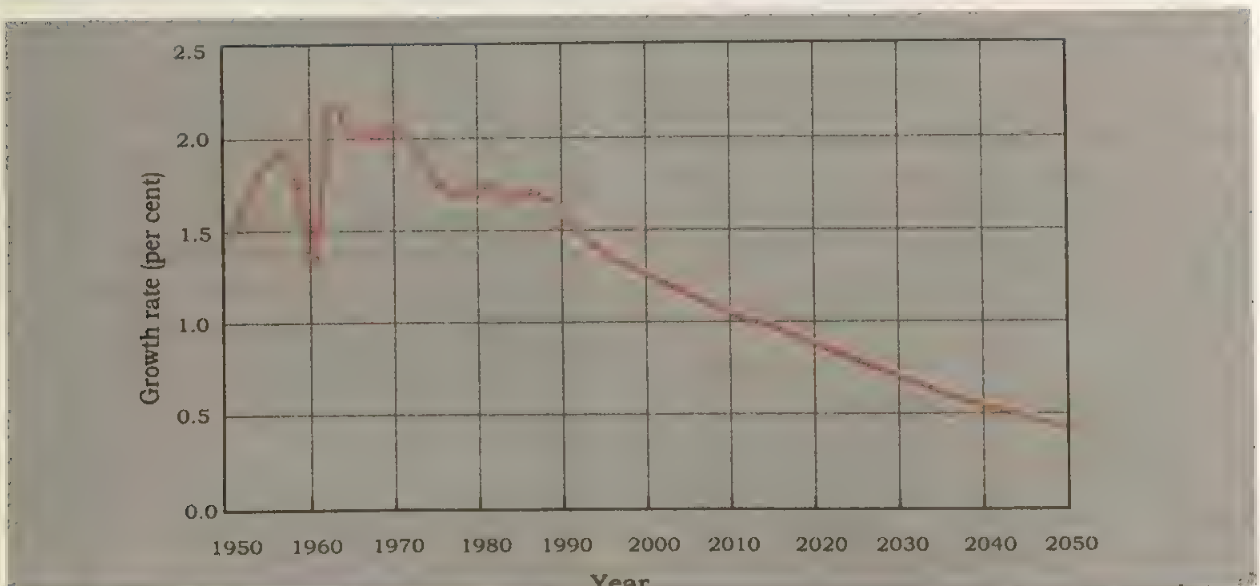


Fig. 22.2 *Projected world population growth rate between 1950 and 2050 (based on United States census bureau, international data)*

size during any period of time, the growth is said to be **exponential** (J-shaped growth curve) (see Chapter 17). When population grows exponentially, utilisation of resources and generation of wastes also grow exponentially. However, the exponential growth in resource use and waste generation cannot continue indefinitely. Figure 22.2 illustrates a "standard" prediction for human population growth, assuming that environmental degradation will ultimately determine the sustainable population level.

22.2 Environment and Human Population Pressure

The increased levels of environmental degradation experienced today arise from the following. Firstly, the world population has increased dramatically, and secondly, population densities within different parts of the world are markedly different.

About half of the 6.1 billion people live in poverty, and at least one-fifth are severely undernourished or malnourished. It is estimated that it takes 15-20 times as much resource to raise a child in the U.S.A as in a developing nation. An important related fact is that 15 per cent of the world's population controls about 85 per cent of the resources. This imbalance is connected to the demographic transition in developed countries (section 22.4). This process has led to aggressive natural resource acquisition and colonialisation.

Developing nations, like India, contain the majority of the world's population. They also have a large rural population, which is shifting to thickly populated urban areas in search of material wealth. Typically, urban areas produce little food, consume more natural resources, and generate more waste products per capita than rural areas. In most cases, urban wastes are hazardous and contaminate the environment with compounds that are foreign to natural ecosystems, and are less subject to natural degradation. Increased urbanisation also puts pressure on agriculture to produce more food on less land, leading to increased pollution by intensive agriculture practices. Thus, the huge human population pressurises and degrades the environment physically, chemically, biologically, and even ethically.

22.3 Development and Environment

Development of human society from hunter-gatherer to agriculture-based society, and finally to the technology-dependent society, has evidently changed the global environment. The extent of resource exploitation is determined by the size of human population, socio-economic structure and technological advancement of a country. Technological advancement causes an increasing detachment of the society from nature, and interferes with the physico-chemical and biological interactions in the environment. Increased exploitation of resources in the form of excessive deforestation, intensive agriculture, indiscriminate mining operations and thoughtless use of fossil fuels, etc., deplete the environment. In such a society, production processes are more capital- and energy-intensive and less labour-intensive. Rapidly growing population demands more resources and is seldom concerned about the consequences of resource acquisition and use.

Development cannot thrive on degraded environment and depleted resources. The issues of development versus environment have led to the concept of sustainable development. The most widely quoted definition of **sustainable development** is the "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". Sustainable development encourages a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development and institutional changes are all in harmony. Such development enhances both present and future potential to meet human needs and aspirations. The concept of sustainable development, thus, aims at a framework to integrate developmental strategies and environmental policies at local, national and global levels. Development should not endanger the natural systems that support life.

22.4 Human Population Growth

Human population growth rate is measured as the *annual average growth rate*, which can be calculated as follows :

Average annual growth rate (in per cent) =

$$\left(\frac{P_2 - P_1}{P_1 \times N}\right) \times 100$$

where,

P_1 is population size in the previous census;
P_2 is population size in the present census; and
N is number of years between the two census.

Census ascertains the number of individuals present in a given region at a given time. The time required for a population to double itself is called the **doubling time**. Annual average growth rate and doubling time are the two important indicators of the pace of population growth. The current growth rate of approximately 1.6 per cent per year for India is smaller than the peak of about 2.1 per cent per year during 1965-1970. Growth rate depends on several factors, such as rates of birth, death, migration, and age-sex ratio.

Fertility

It is the ability of the reproductively active individuals to produce babies. Fertility is the determinant of the current growth of population. **Birth rate** is the number of babies produced per thousand individuals. It is distinct from the population growth rate as it can never be negative, while the latter can be negative. Birth rates, however, do not indicate the current fertility pattern. **Total fertility rate** (TFR) is the average number of children that would be born to a woman during her lifetime, assuming the age-specific birth rate of a given year. **Replacement level** (RL) is the number of children a couple must produce to replace themselves. The actual RL is always slightly higher than 2.0 since some children will die before reaching reproductive age. In developed countries, RL is at 2.1, whereas in the developing countries, it is around 2.7 due to a higher death rate at the immature age, and shorter life expectancy.

The total fertility rate varies from region to region. The more developed countries have lower fertility rates (close to replacement levels) than the less developed countries. Fertility is largely controlled by economics and by human aspirations. Frequently, the high fertility in the developing world is partially explained by the large number of hands needed to perform low-technology tasks. As the technology improves, parents realise that having more children leads to lower standards of living. This realisation leads to a lower total fertility rate.

Mortality

Mortality is the death rate per thousand individuals. In most countries, the death rate has dropped almost continuously since the industrial revolution, mainly due to improved personal hygiene, sanitation, and modern medicine. A decrease in death rate would result in increased population growth rate.

Demographers usually employ ***crude birth rate*** and ***crude death rate***, which are the numbers of live births and deaths per thousand persons, respectively, in the middle of a given year, i.e., on July 07. The difference between the number of births and that of deaths is the **rate of natural increase**. If birth and death rates were equal, a zero population growth rate would result, which is called **demographic transition**. Demographic transition might occur in all countries as they become developed, but it may take many decades. Figure 22.3 shows the different stages of the demographic transition.

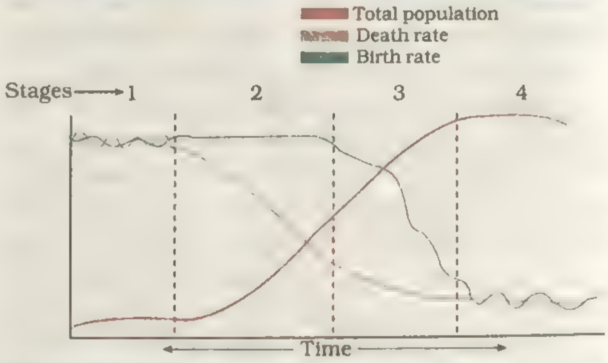


Fig 22.3 *Different stages of the demographic transition :*

1. *High birth rate but fluctuating death rate;*
2. *Declining death rate and continuing high birth rate;*
3. *Declining birth and death rate;*
4. *Low death rate but fluctuating birth rate*

Migration

Migration is the movement of individuals into (**immigration**) or out of (**emigration**) a place or country. Migration may also occur within a country, from one region to another. But only between-country migration influences a nation's population. Only the **net immigration**, i.e., immigration minus the emigration, is added to the population growth by birth. The net immigration may be positive, zero or even negative.

Age and Sex Structures

The age structure of a given population refers to the proportion of individuals of different ages within that population. This aspect is important because many functional aspects of the individuals are related to age. For example, infants below one year of age, and the older people have higher mortality rate than individuals of other ages. In addition, the proportion of reproductively active males and females in a population influences the population growth. The number of female individuals in active reproductive age (usually 15-44 years) influences the birth rate within a population.

Age-sex structure of a population can be depicted in the form of a pyramid diagram by plotting the percentage of population of each sex in each age-class. Figure 22.4 shows

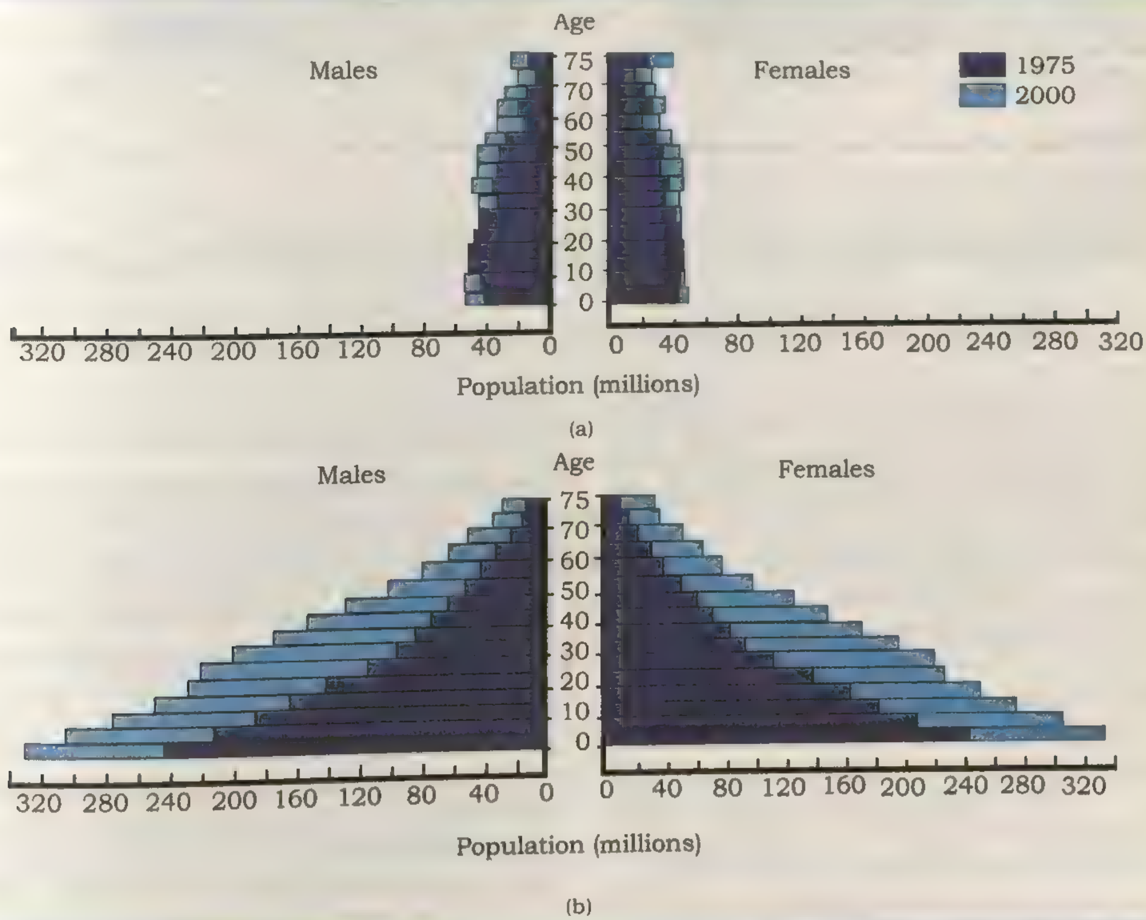


Fig. 22.4 Age-sex pyramids between 1975 and 2000 : (a) Developed countries, (b) Developing countries

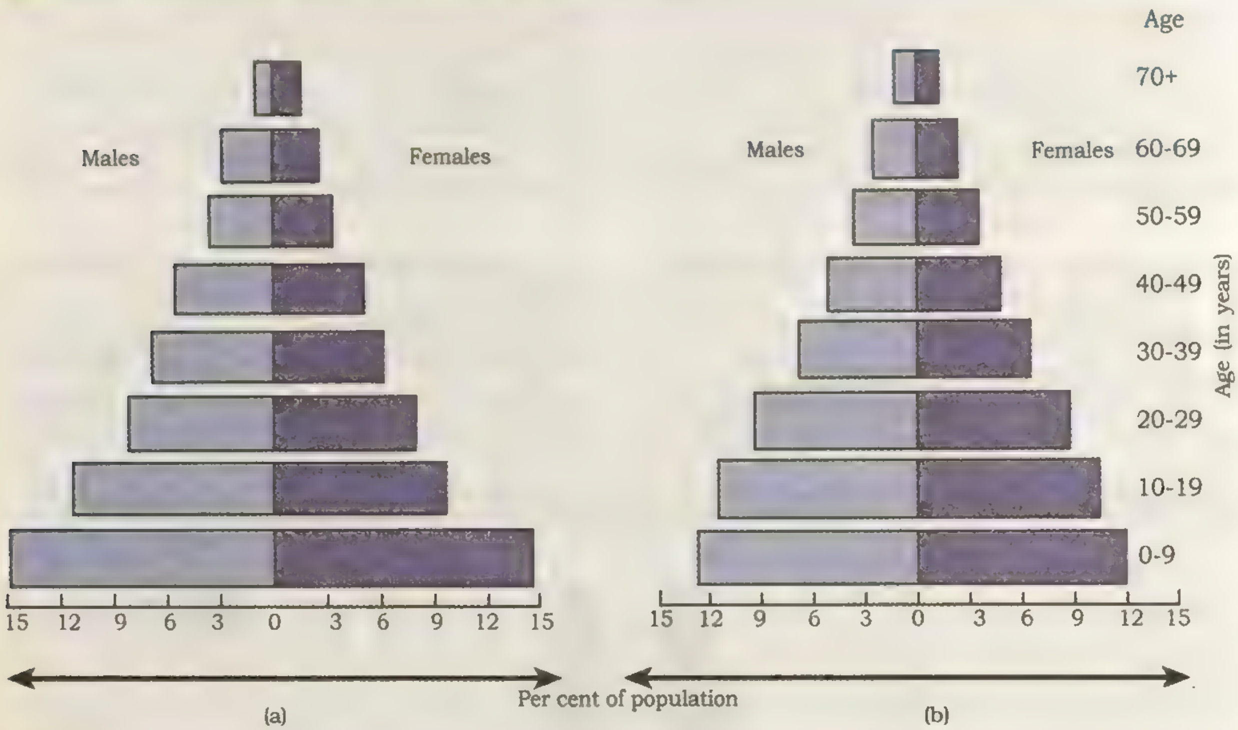


Fig. 22.5 *Comparative age-sex pyramids for India : (a) Year 1971, (b) Year 1991*

the age-sex pyramid for the developed and developing world for the years 1975 and 2000. The age-sex structure of the developed world gives a steeper pyramid, which represents a nearly stable population. In contrast, a rapidly growing population, like that of India, is represented by a much less steep pyramid, as it has a much larger number of young people. The female side of the diagram is particularly important in understanding future growth. Figure 22.5 illustrates the changes in the shape of age-sex pyramid for India over the 20-year period from 1971 to 1991. The population planning policies have succeeded only marginally. The pyramid for 1991 has a long way to go before it resembles that of a stable population. Clearly, population control is a challenging task requiring persistence and patience.

22.5 Human Reproductive Health

Young people will determine the size, health, and prosperity of the world's future population. At the turn of the new century, 1.7 billion people were between the age of 10 and 24 years, and the vast majority lived in less developed countries. Young people's needs vary tremendously, depending on the stage of life, viz., puberty, adolescence, and early adulthood, and on the context in which they live. Health and education of young people, and marriage and childbearing during more mature stages of life, are important attributes to the reproductive health of a society. Some crucial concerns are as follows :

(i) Secondary school enrolments are still low in many parts of the world, and enrolments of girls lag behind those of boys.

(ii) Complications of pregnancy, childbirth, and unsafe abortion are the major causes of death of women between the age of 15 and 19 years.

(iii) Young people (15 to 24 years) have the highest infection rates of sexually transmitted diseases (STDs), including AIDS.

Women with more education tend to be healthier and more prosperous, and have fewer and healthier children. Early pregnancy and child-bearing are typically associated with less education and lower future income for young mothers. Young women (15 to19 years) and their children face serious health risks. Since such women have not completed their growth, in particular height and pelvic size, they are at a greater risk of obstructed labour (when the birth canal is blocked), which can lead to permanent injury or death of both the mother and the infant. Infants of young mothers are more likely to be premature and have low birth weights.

Cultural standards of acceptable sexual behaviour for young people complicate the issue of adolescent reproductive health. Reproductive health programmes for young men, primarily encourage responsible sexual behaviour. They can also support other positive behaviours and attitudes, such as staying in school, and re-examination of gender roles and responsibilities. They can encourage boys to support their female partners in the latter's reproductive health needs and decisions, and to avoid violence and abuse of drugs and alcohol.

22.6 Adolescence

Adolescence is the period of rapid growth, physical and mental development poised between childhood and adulthood, i.e., the period between 8-18 years for girls, and 7-19 years for boys. This period extends from puberty (appearance of the first external signs of sexual maturation) to complete sexual maturity. Adolescence is marked by accelerated physical growth, development of reproductive organs, and changes in functioning of the neuroendocrine system. Adolescents experience frequent shifts of moods and emotional turbulence prompted by increased production of hormones, including sex hormones. This comes at a time of preoccupation with self-assertion (egocentrism), and concurrent developments in self-identity, self-esteem and self-respect. A rational, positive and accurate understanding of self in relation to siblings, peer groups in school and rest of the world is important for social adjustments, particularly under the conditions of stress and conflicts. Moral reasoning develops in adolescents, regardless of their culture and their religious background.

Common Problems of Adolescence

The most common problem of almost all adolescents of both the sexes is acne. Acne results from clogged pores of skin due to a side effect of the influx of sex hormone, androgen. This unsightly skin complaint increases self-consciousness, especially if it appears on the face. Adolescents, especially 'late developers', often suffer from anxiety and a psychosomatic disorder, called **hypochondria** (undue concern about health).

Adolescence is also the time of social awkwardness and exhibitionism, and aggressive self-assertion. Socially and emotionally, adolescents experience alternate periods of loneliness (withdrawal from the social surroundings) and gregariousness (tendency to be with the social surroundings). Some adolescents may develop a fixation for weight control and an inability to consume food. On the other hand, some young adults may have an irresistible craving for food, leading to overeating. In some cases, physiological aberrations, including absence of monthly periods in females or perceptual disturbances, may also occur. **Neurasthenia** is characterised by the inability to concentrate on or enjoy things, and may lead to irritability, fatigue, insomnia, depression and headache.

Phobias are also common in adolescents. Phobias are intense dread of things or creatures, for example, creepy crawlers like spiders or snakes, or situations like crowded places, vast open places, closed small

chambers, etc. Adolescents may also suffer severely from **post-traumatic stress disorder** due to traumatic experiences like rape or robbery. In such cases, surviving victims and bystanders are affected equally. Addiction to drugs, alcohol, tobacco smoking and chewing is also common among adolescents. Advertisements, curiosity, peer-pressure, frustration and depression, feeling of independence, false belief of enhanced physical, mental and/or intellectual performance, may be some of the reasons for such addictions.

Social and Moral Implications

Adolescence is the formative period of both physical and psychological health and is the preparatory phase for the adult life. During this period, an individual moves out from the familial periphery and begins to identify and define his/her position in relation to the outer world. Further, he or she undergoes physiological and behavioural transformations, and acquires higher levels of moral standings. Thus, a healthy adolescence is critical for a healthy adulthood.

22.7 Mental Health

Mental health is important for the maintenance of physiological health, and social effectiveness. It involves the ability to balance feelings, desires, ambitions and ideas, and to face and accept the realities of life. In contrast, mental illness prevents adjustments with the society. For example, solitude is healthy withdrawal, but depression is unhealthy.

Mental illness is characterised by the following symptoms : (i) depression, (ii) insomnia (lack of sleep) or excessive sleeping, (iii) compulsive actions, (iv) feeling of hopelessness, (v) serious thoughts of suicide, (vi) unreasonable phobias, (vii) partial or complete loss of memory, (viii) self-destructive behaviour, e.g., excessive gambling, drinking, drug abuse, over-eating and extreme dieting, (ix) delusions (false beliefs) and hallucinations, and (x) vocational and social dysfunctioning on a day-to-day basis. **Hallucination** is a subjective disorder of sensory perception, in which one of the senses is involved in the absence of external stimulations.

Psychological Disorders

These include psychosis and neurosis. **Psychosis** involves deeper mental disorientation due to a distorted sense of reality. **Neurosis**, on the other hand, is a maladaptive habit. Neurotic individual relates to the same "real world" as does the normal, but cannot effectively act upon it. Important psychological disorders are as follows :

(i) ***Anxiety disorders*** : These are a diverse group of disorders. Neurotic anxiety develops when there is an over-reaction to stressful events. It is associated with a range of unpleasant bodily symptoms, including palpitation, sweating, nausea, trembling, diarrhoea and muscular tension. The commonest anxiety states seen in childhood and adolescence are separation anxiety disorder and school phobia.

(ii) ***Obsessive-compulsive disorders*** : These disorders cause total disability and affect a person's waking hours. Affected persons manifest overwhelming obsessions and compulsions. They are compelled to perform an action or an idea despite their own attempt to resist it (compulsion). The most common obsessions are violence, concern about infection by germs or dirt, and constant doubts (obsessions).

(iii) ***Attention deficit disorder*** : It is a mental health problem among children. It occurs more in boys than in girls. As a result of this disorder, the boys exhibit underachievement, behavioural problems and a tendency to be disliked by other children.

(iv) ***Mood disorders*** : These are the occasional bouts of high or low mood, i.e., elation and depression. **Depression** is a mood disorder characterised by sadness, hopelessness, low self-esteem, decline in interest, energy, concentration and changes in sleep pattern and appetite. The cause may be a death in the family, failure in examination or interview, or losing of a job. This disorder can be

bipolar, i.e., depressed mood may alternate with exaggerated arousal and overactivity, like non-stop and quick talking, taking multiple tasks at the same time, etc. Endogenous depressions arise from internal biochemical or genetic factors; their symptoms are lethargy, self-hatred, exhaustion, erratic sleep pattern and uncontrollable weeping.

(v) ***Schizophrenia*** : It is characterised by (a) distorted thoughts, (b) laughing or crying at completely inappropriate times, (c) often disturbed emotions with rapid shifts from one extreme response to other, and (d) incoherent and bizarre behaviour lasting for a week or more. Schizophrenics may also suffer from delusions, auditory hallucinations and can find difficulty in handling even the simplest jobs.

(vi) ***Borderline personality disorder (BPD)*** : This disorder is an emotionally unstable personality disorder, which is characterised by impulsivity, unpredictable moods, outbursts of emotion, behavioural explosions, quarrelsome behaviour, and conflicts with others. BPD can be diagnosed with specific patterns of behavioural, emotional, and cognitive instability and dysregulations. These individuals are highly reactive, and generally experience episodic depression, anxiety, and irritability. They also have problems with anger and anger expression. Relationships with other individuals are chaotic, intense, but nevertheless, hard to give up. Individuals with BPD often attempt to injure, mutilate, or kill themselves, and have little sense of self since they feel empty.

Addictive Disorders

Addictive disorders bring about a state when the body requires continuous presence of a psychoactive substance within it. **Psychoactive drugs** have the ability to alter the activity of nervous system. Narcotics like opium, psychomotor stimulants like cocaine, amphetamine (synthetic analogue of adrenalin), caffeine and nicotine, sedatives and antidepressants, alcohol, hallucinogens

Table 22.1 : Major Categories of Psychoactive Drugs, their Effects and Clinical Uses

Type of drug	Examples	Effects	Clinical Uses
Sedatives and tranquilisers (depressant)	Barbiturates Benzodiazepines (e.g., Valium)	Depress brain activity and produce feelings of calmness, relaxation, drowsiness and deep sleep (high doses)	Hypnotic, antianxiety
Opiate narcotics	Opium, morphine, heroin, pethidine, methadone	Suppress brain function, relieve intense pain (physical and mental), produce temporary euphoria	Analgesic
Stimulants	Caffeine (very mild), amphetamines (including dexamphetamine), cocaine and its derivative novacaine	Stimulate the nervous system; make a person more wakeful, increase alertness and activity, produce excitement.	Attention deficit, narcolepsy, weight control
Hallucinogens	LSD, mescaline, psilocybin, charas, hashish, marijuana (bhang)	Alter thought, feelings and perceptions; hallucinations	None

like lysergic acid diethylamide (LSD), marijuana and phencyclidine are some of the most commonly abused psychoactive drugs. These drugs are normally used as medicines to help patients cope with mental illnesses like depression, insomnia and so on. But when they are taken for a purpose other than their normal clinical use in an amount, concentration or frequency that impairs one's physical, physiological and psychological function, it constitutes **drug abuse**.

Several drugs of abuse and their effects are listed in Table 22.1. These drugs have drug-seeking or addiction behaviour as a common feature. **Sedatives** and **tranquilisers** depress brain activity, and produce a feeling of calmness, relaxation or drowsiness. In higher doses, they induce sleep. **Opiate narcotics** suppress pain, reduce anxiety and tension, cause lethargy, and produce a feeling of well-being. Addiction to opium leads to loss of weight and interest in work.

Stimulants increase alertness and activity, and may produce excitement. There are chances of psychological dependence on stimulants, but physical dependence usually does not occur. **Hallucinogens** can alter a person's thoughts, feelings and perceptions. The sensations may be pleasant or, more usually, unpleasant. Some of these drugs, e.g., LSD, cause chronic psychosis and damage the central nervous system. The habitual non-medical use of an addictive drug (**drug dependence**) often leads to altered consciousness and/or perception.

If a habitual user terminates taking a drug (**abstinence**), his body ceases to function normally (**physical dependence**). A whole complex of unpleasant withdrawal symptoms and rebound are experienced. The withdrawal symptoms may range from mild tremors to convulsions, severe agitation and fits, depending on the type of drug abused. In some cases, withdrawal symptoms can be very severe and even life-threatening, and the person may need medical supervision during the withdrawal period.

Psychological dependence stems from a craving, i.e., an overwhelming desire experienced when the user encounters the stimulus, e.g., smell of a cigarette, associated with the abused substance. An abrupt abstinence also causes craving. Some drugs produce only physical dependence, while others produce both physical and psychological dependence. Psychological dependence is often much more difficult to overcome than physical dependence.

Table 22.2 : Interaction of Alcohol and other Substances of Abuse with Some Common Drugs

Drugs	Effects
Alcohol and other depressants, e.g., barbiturates	Dramatically increased depressant effect
Alcohol + Antihistamines	Marked drowsiness
Alcohol + Benzodiazepines	Rapid increase in sedative effect; often dramatic
Alcohol + Marijuana or Hashish	Decreased coordination, increased reaction time, impaired judgement
Alcohol + Aspirin	Increased risk of damage to gastric mucosa
Benzodiazepines + Barbiturates	Increased sedation
Amphetamine + Insulin	Decreased insulin effect
Nicotine + Cocaine	Increased cardiovascular effects
Cocaine + Antidepressants	Hypertension

The drugs of abuse are often taken with alcohol or some common medicines, e.g., aspirin, etc. Such a combined use often increases sedation, in some cases reduces the effect of medicine, or may even cause complications like hypertension (Table 22.2).

Drug abuse is not found among well-adjusted, satisfied and happy people. It is more common among those who are under stress, and feel insecure. These people are usually not satisfied with themselves, and wish to assume imaginary personalities. Problems and stresses are becoming increasingly more common in modern life. Therefore, people should learn to face the problems and stresses, and accept disappointments and failures as normal parts of life. It is also advisable to discuss the problems with family members and friends and attempt to sort them out, rather than to resort to drug or alcohol use.

22.8 Population as a Resource

Human resources are the capabilities of human beings to generate useful products and services. They form the most unique elements of our social and physical milieu. Human resources are very important as they produce other resources, like intellectual, social, economic and political resources. Therefore, a healthy and capable future generation is the first and the foremost pre-requisite for the development and prosperity of any nation. Humans can not only generate resources, but they are also instrumental in conserving the existing resources. The latter function is perhaps the exclusive ability of human resource because humans can think and act rationally. Human resources can, therefore, maximise natural resource utilisation in a sustainable manner.

SUMMARY

Human population has followed an exponential growth pattern at an accelerated pace over the past few centuries. The size of the population is determined by carrying capacity of the environment. The carrying capacity is being increased by application of science and technology. There is a lot of pressure of exploding human population on the environment, which is being degraded. There is a need of sustainable use of environment. Population growth is determined by fertility, mortality migration, age-sex structure. The specific growth rates are dependent on the level of development in a specific century. Medical advances and improved sanitation have led to decrease in death rate in the developed countries.

Adolescence is a formative period of both physical and physiological health. There are several problems, such as acne, phobias and post-traumatic stress disorders faced by adolescents. Mental health is an important aspect of physiological health and social effectiveness. Mental illness has symptoms of psychological disorders and addictive disorders. The youth are tempted to go for drugs for non-clinical use. Drug abuse is on the rise among the youth due to several factors, like tension and peer group pressure. A sound psychological and reproductive health is essential for the population to become a resource.

EXERCISES

1. What is the annual average growth rate?
2. What is doubling time with reference to population growth?
3. How does total fertility rate influence population growth?
4. What would be the basic intention to encourage each couple to restrict to have two children only?
5. Briefly explain 'crude birth rate' and 'crude death rate'.
6. What is demographic transition?
7. Distinguish between immigration and emigration.
8. How can age-sex structure of a population be depicted in a pyramid diagram?
9. Briefly outline the reasons for human population explosion.
10. Define sustainable development.
11. Write true or false :
    (a) Adolescents often abuse drugs out of curiosity and peer pressure.
    (b) Nicotine is a narcotic.
    (c) Abstinence from drugs of dependence causes withdrawal symptoms, but not craving.
    (d) LSD is a hallucinogen.
    (e) Adulthood precedes adolescence.
12. List at least five symptoms of mental illness.
13. How does neurosis differ from psychosis?
14. Briefly state five common problems of adolescence.
15. Write short notes on :
    (a) Total fertility rate
    (b) Drug abuse
    (c) Replacement level
    (d) Anxiety disorder
    (e) Schizophrenia.

Chapter 23

GENETIC IMPROVEMENT AND DISEASE CONTROL

Humans derive their nutrition from plants and animals. They have also begun to use micro-organisms as food. Initially, humans hunted wild animals and collected fruits from wild plants. Much later, they began to cultivate plant species and raise animals under their supervision. It is believed that agriculture began a little over 10,000 years ago. **Domestication** is the process of bringing a species under human management. This is the very first step in the various activities that aim at enhancing food production. You had learnt in earlier classes about cultivation of crops and raising of animals. In this chapter, we will focus on their genetic improvement, along with the control of important diseases of crops and animals, which are very useful in increasing food production and food quality.

23.1 PHENOTYPE

Performance of a crop or an animal depends mainly on its genotype and the environment in which it is grown (Fig. 23.1). **Genotype** is the genetic make up (genes present) of an individual or a variety. In contrast, the **environment** includes all living and non-living factors that surround the individual or the variety in question. The genotype determines the ability of an organism to perform well. The environment, on the other hand, either allows or does not allow this ability to be expressed. We may elaborate this with the help of a simple example. Different individuals in your class are likely to differ for their skin colour. This may be due to differences in their genotypes. However, the skin colour of the same person becomes darker when he or she spends more time in the sun. In contrast, the skin colour becomes lighter when he or she spends less time in the sun. Clearly, this variation in skin colour arises due to the environmental influences. Thus, both the environment and the genotype are important in the development of phenotypes, i.e., the observable features of an organism. Therefore, maximisation of food production would involve the improvement in crop or animal genotypes, as well as the environments under which the crops and animals are raised.

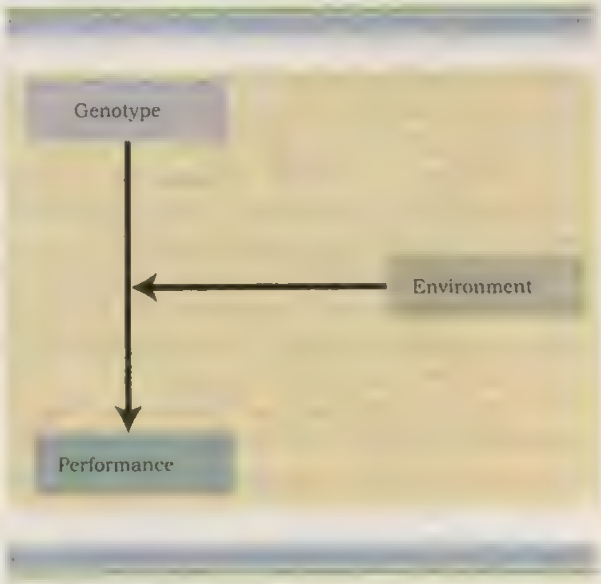


Fig. 23.1 *A simplified representation of the relationship between performance, and genotype and environment. Performance may be taken as yield*

Improved Management Practices

You are familiar with cultivation of crops and raising of animals. You have learnt that plants require carbon, oxygen, hydrogen, nitrogen, phosphorus and several other elements that are obtained from the environment (air, water and soil). Appropriate quantities of manures and fertilisers have to be applied to meet the mineral nutrition requirements of crops. In addition, adequate irrigation needs to be provided, and weeds and diseases must be controlled for obtaining good yields.

You have also studied about some important diseases of cattle and their control measures. You will realise that the various practices mentioned here modify the environment in which the crops or animals are raised. These are called **improved management practices**. We will later discuss the control of animal and plant diseases.

Improvement in Genotype

During the process of domestication, humans would select traits that were useful to them. For example, wild species generally produce a larger number of rather small seeds. Humans, on the other hand, prefer larger seeds and fruits. The pods of wild plants shatter at maturity, but this is not useful to humans. Thus, the traits preferred by human beings are generally distinct from those favoured by nature. Therefore, humans tended to select for traits like larger fruits and seeds, non-shattering pods, etc. in the domesticated populations. A **trait** or **character** is any morphological, anatomical, biochemical or behavioural feature of an organism. Thus, fruit or seed size, seed yield, etc. are examples of traits. **Selection** is the process that leads to different rates of reproduction by different genotypes present in a population.

Continued selection has changed our crops remarkably as compared to their wild relatives. As a result, the crop plants are very useful to humans. In contrast, the wild relatives of crops are mostly weeds. When genotype of an organism is modified to make that organism more useful to humans, the process is called **breeding**. **Plant breeding** is concerned with improvement of crops. Similarly, **animal breeding** aims at genetic improvement of domesticated animal species.

23.2 Improved Varieties

A **variety** consists of a group of plants that have the same genotype or similar genotype, and it differs for one or more characters from other varieties of the same crop. A variety is recognised as such only when it is released for cultivation. An **improved variety** is superior to the other existing varieties of the same crop in respect of one or more characters. As you already know, a crop variety must possess several desirable characters, like high yield, superior quality, early maturity, resistance to important diseases and insect pests, etc. An improved variety is recognised as such by a variety release committee based on its detailed evaluation for yield and other characters. But before evaluation, a new variety has to be developed by a systematic breeding effort.

23.3 Development of New Varieties

The development of a new variety is a prolonged activity requiring various resources. It took twelve years to develop the wheat variety *HUW 468* through hybridisation (Fig. 23.2). Variety development consists of the following

Fig. 23.2 *Photograph of an improved variety (HUW 468) of wheat (Courtesy : Dr. Arun K. Joshi)*

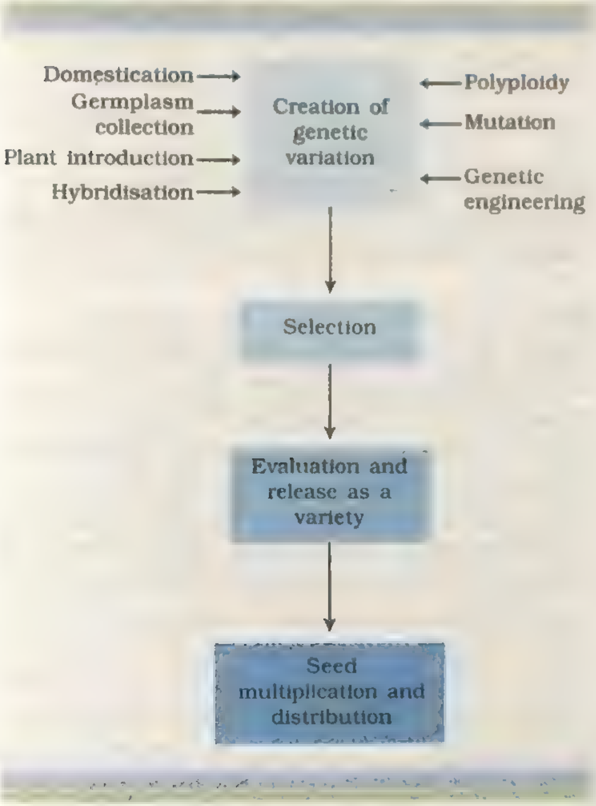


Fig. 23.3 *Different activities in plant breeding*

main steps : (i) creation of genetic variation, (ii) selection, (iii) evaluation and release as a variety, and (iv) seed multiplication and distribution to farmers (Fig. 23.3). These steps are described in details in the following subsections.

Creation of Genetic Variation

The two critical steps in plant breeding are : (i) creation of genetic variation, and (ii) selection.

Genetic variation provides the raw material for selection, whereas selection effects the desired improvement. The differences among individuals of a population or species for a given character constitute **variation** for that trait. For example, consider the heights of individual students in your class. The differences in height constitute variation for height in this group of students. A part of this variation arises due to genetic reasons, i.e., differences in genotypes of the individuals. This part of variation is called **genetic variation,** which is passed on from parents to their progeny, i.e., it is heritable. A **heritable variation** arises due to genotype and is useful for selection. The remaining part of variation is due to factors other than genotype. It arises due to the environment, but is not heritable, and useful for selection.

Any character of a crop (or any species) can be improved only when genetic variation is present for the character. Let us suppose that we desire to increase the length of rice grain. If all the rice plants in the world produced grains of the same length, how can we select for longer grain? Therefore, success of a breeding programme usually depends on creation of the desired genetic variation. This can be done in several ways. (i) domestication, (ii) germplasm collection, (iii) plant introduction, (iv) hybridisation, (v) polyploidy, (vi) mutation, and (vii) genetic engineering. Domestication gives us new crops. Humans have already domesticated many of the useful plant species. But some new plant species are still being domesticated. Germplasm conservation, plant introduction, polyploidy and mutation are considered later in this chapter. Genetic engineering is considered in the next chapter.

Hybridisation is the most common method of creating genetic variation. Mating between two (or more) individuals or lines differing in genotype is called **hybridisation**. A **line** consists of a group of individuals related by descent, and often similar in genotype. The individuals/lines used in hybridisation are called **parents**. The choice of parents is critical to the success of a breeding programme and is done with great care. One of the two parents is used as female, while the other is used as male. Before the flowers of the female parent open and shed pollen, their anthers are carefully removed; this is called **emasculation**. This prevents self-pollination in these flowers. Now, pollen is collected from the flowers of male parent and placed on the stigma of these flowers. The seeds produced by these flowers of the female parent are the **hybrid** or ***F1* seeds**. There will be segregation, independent assortment and recombination in the *F2* and

later generations obtained from these *F1* seeds. These will produce genetic variation. The amount and the kind of genetic variation produced will depend on the genetic differences present between the parents used in hybridisation.

Most often, different lines or varieties of the same species, e.g., different varieties of wheat, are mated. Such matings constitute **intervarietal hybridisation**. But sometimes, a crop species is mated with a different related species. This is known as **interspecific hybridisation**. Interspecific hybrids are ordinarily difficult to produce as well as use. But they are important in plant breeding, particularly in breeding for disease resistance. Some interspecific hybrids are even used as varieties. For example, all the sugarcane varieties being cultivated today are interspecific hybrids.

Selection

A breeder selects from a population such plants that have desirable characteristics. Seeds from only the selected plants are harvested and used to raise the next generation. Rest of the plants are ordinarily rejected. This process is called **selection,** and is the step that brings about improvement in the crop. Therefore, the extent of improvement in a character depends mainly on the effectiveness of selection. Selection utilises the genetic variation present in a crop. Thus, selection can be effective only when genetic variation for the characters is present in the crop being improved.

We return to the example of grain length in rice. Let us suppose that we used hybridisation to produce a population of rice plants that shows genetic variation for grain length. In this population, some plants will have longer grains, whereas the others will have intermediate or shorter grains. Therefore, the average grain length for this population will be much smaller than the length of grains produced on the superior plants. Improvement in grain size will occur only when we select those plants that produce the longest grains and use their seeds to grow the next generation. The selected population of rice plants will have, on average, longer grains than the original population. Thus, selection acts on the genetic variation present in a population and produces a new population with improved characters.

Selection in self-pollinated crops : Crops are classified into the following two broad groups : (i) self-pollinated, and (ii) cross-pollinated. As you know, in the case of self-pollination, pollen from a flower lands on the stigma of the same flower. Cross-pollination occurs when pollen grains from a flower get deposited on the stigmas of flowers on other plants. In **self-pollinated crops**, the amount of cross-pollination is less than 5 per cent. Self-pollination causes a rapid increase in homozygosity. As a result, populations of self-pollinated crops are mixtures of different homozygous genotypes. Selection in such crops, therefore, ultimately isolates the best homozygous genotype present in the population. This genotype may be used as a new variety. For example, the wheat variety HUW 468 shown in Figure 23.2 is a pure line. Such varieties are maintained by self-pollination and farmers can grow their seeds year after year. The self-pollinated progeny of a homozygous plant constitute a **pure line.** All the plants in a pure line have identical genotype. Therefore, variation present within a pure line is due to the environment and has no genetic basis. The varieties of self-pollinated crops are ordinarily pure lines.

Selection in cross-pollinated crops : Populations of cross-pollinated crops are heterozygous for most of their genes. Any decrease in heterozygosity reduces their performance. Therefore, homozygous genotypes cannot be used as varieties in such crops. A cross-pollinated population contains plants of several different genotypes. Some of these genotypes are superior, but many are inferior. Selection in such crops aims at increasing the frequency of superior genotypes without reducing heterozygosity. The new population obtained after selection, therefore, shows improved performance. But this population also remains highly heterozygous and contains many different genotypes.

Therefore, selection can be continued in the successive generations of cross-pollinated crops.

Evaluation and Release of Varieties

A newly developed pure line, improved population or hybrid, undergoes critical evaluation for yield, quality, disease and insect resistance and for other traits, before it is released as a variety for cultivation in a given region. In India, Indian Council of Agricultural Research (ICAR), New Delhi, carries out the evaluations. The materials developed by many breeders are evaluated together at several locations in different agroclimatic zones. The whole country is divided into agroclimatic zones on the basis of soil and climatic conditions. The number of these zones depends on the crop in question. Each material is evaluated in a single agroclimatic zone for at least three years.

In every evaluation, performance of the new materials is compared with that of the existing varieties; they are also compared with each other. A new pure line, population or hybrid, that is superior to the existing varieties, as well as to other new materials may be released as a new variety. The breeder of such a material makes a proposal for its release. This proposal is then considered by a variety release committee. If the proposal is accepted, the new material is given a name and is released as a new variety. The government notifies each new release.

Multiplication of Improved Seed

The benefits from a new variety can be realised only when farmers grow it. Therefore, seed of a new variety must be multiplied and made available to the farmers. In plant breeding, the term seed is not confined to the botanical seed that develops from ovule. Here, **seed** means any plant part that is used to grow a crop. Thus, 'seed' would include grains of wheat, rice, etc., tubers of potato, stems of sugarcane, etc., provided they are used for producing new plants. Therefore, wheat grains used as food cannot be termed as seed, whereas those used for raising a crop are called seeds. Seed of a variety with superior traits is called improved **seed**, which must be of high purity and have a high germination percentage. It must also be free from weed seeds and from diseases.

Anyone selling seed must put a proper label on it, such as shown in Figure 23.4. The label must carry information about the above mentioned features of the seed. The quality of seed must match the information given in the label. The quality of seed is often certified by an agency; when this is done, the seed is called **certified seed**. National Seed Corporation (NSC) was established to streamline seed production in India; it continues to play a central role in seed multiplication.

Fig. 23.4 *The label used by National Seed Corporation (NSC) for the seed of Hi-starch hybrid maize*

23.4 Germplasm Collection and Conservation

Germplasm is the sum total of all the alleles of the genes present in a crop and its related species. Thus, the germplasm of any crop species would consist of the following types of materials :

(i) cultivated improved varieties,
(ii) improved varieties that are no more in cultivation,
(iii) old local or 'desi' varieties,
(iv) lines produced by plant breeders, and
(v) wild species related to the crop species.

All these materials contain valuable alleles of genes that are important in breeding. In fact, germplasm is the building material out of which improved varieties are constructed. A good germplasm collection is essential for a successful breeding programme. Thus, collection of germplasm from various sources is one of the first steps in any systematic breeding programme.

In primitive agriculture, each variety was highly variable and served as store-house of genetic variability. But modern-day agriculture uses improved varieties that are more or less genetically uniform. The old varieties have now been mostly replaced by more uniform new varieties. In addition, expansion of agriculture, industries and other human activities are damaging wild relatives of crop plants. All these factors are causing loss of genetic variability, i.e., germplasm. Germplasm collection is the most practical and effective answer to this problem.

Germplasm is collected from within the country, as well as from other countries. The germplasm collections are usually maintained at a low temperature in the form of seeds. The stored seeds are grown periodically in the field to obtain fresh seeds. This becomes necessary because the per cent seed germination decreases with storage time. But in the case of fruit trees, the germplasm is maintained as trees grown in the field. In such cases, plant tissue culture can be used to maintain germplasm in test tubes as shoot cultures.

When a variety, line or population of a plant species is taken from one area into a new area where it was not grown before, it is called **plant introduction** or simply **introduction**. Introductions from other countries are valuable sources of germplasm. Such introductions have given us many of our valuable crops, e.g., potato, tomato, cauliflower, grapes, guava, etc. Soyabean is an example of a recently introduced crop. Introductions have also provided us with improved varieties. 'Sonora-64' variety of wheat and 'Taichung Native 1' rice variety are introductions. These dwarf varieties provided the starting material for 'green revolution' in India. Most introductions are, however, used in breeding programmes, e.g., as parents in hybridisation.

It should be noted that new weeds, insect pests and diseases could also come into our country along with the introduced materials. *Argemone mexicana* is an example of a weed that entered India with an introduction. Therefore, all introductions are carefully examined for the presence of weeds, insects and disease-causing organisms; this is known as **quarantine**. Only those introductions that are free from the above, are permitted to be used, and the rest are destroyed. Quarantine is also applied to animals and, sometimes, to humans to reduce the risk of entry of a pathogen in the country.

23.5 Inbreeding Depression and Heterosis

When two individuals of a species that are related by descent are mated together, it is known as **inbreeding**. The most extreme form of inbreeding is self-pollination or selfing. A majority of cross-pollinated crops and all animal species show inbreeding depression. On the other hand, none of the self-pollinated crops show the ill effects of inbreeding. **Inbreeding depression** may be defined as the loss in vigour associated with inbreeding.

The most likely explanation for inbreeding depression is as follows. The dominant alleles of all genes have beneficial effects. However, the recessive alleles of most, if not all, genes are deleterious to various degrees. Plants of cross-pollinated species are highly heterozygous. Therefore, they contain recessive alleles of most of the genes in heterozygous state. The harmful effects of the recessive alleles, as a result, will not be expressed. When such a population is subjected to inbreeding, there will be an increase in homozygosity. As a result, many recessive alleles would become homozygous. These recessive alleles will express their

AA BB cc dd x aa bb CC DD

Line A **Line B**

Aa Bb Cc Dd

F1 Hybrid

Fig. 23.5 *Explanation of inbreeding, depression: and heterosis. Lines A and B will show reduced vigour due to the harmful effects of the recessive alleles c, d (in Line A), a and b (in Line B). The hybrid from these two lines will be vigorous because the harmful effects of a, b, c and d will be masked by their dominate alleles due to heterosis*

harmful effects, causing inbreeding depression. As shown in Figure 23.5, lines A and B will show reduced vigour due to the harmful effects of the homozygous recessive alleles *c*, *d* (in Line A), *a* and *b* (in Line B). In self-pollinated crops, on the other hand, alleles become rapidly homozygous, and the deleterious alleles are removed by selection. Therefore, populations of such crops contain few deleterious recessive alleles and, as a result, do not show inbreeding depression.

Heterosis is essentially the reverse of inbreeding depression. When two unrelated individuals or lines are crossed, the performance of *F1* hybrid is often superior to both its parents. For example, the *F1* hybrid, produced by crossing the lines A and B (Fig. 23.5), will be superior to both the parents. This *F1* will be superior because the harmful effects of *a*, *b*, *c*, and *d* alleles will be masked by their dominant alleles. This phenomenon is known as **heterosis**. Almost all species show heterosis.

23.6 Mutation Breeding

Mutation is a sudden and relatively permanent heritable change in a character of an organism. It can arise due to a change in any of the following : (i) chromosome structure, (ii) chromosome number, and (iii) base sequence of the concerned gene. Mutations occur in nature at a very low rate; these are called **spontaneous mutations**. Mutant alleles are generally recessive, and produce harmful effects. Only about 0.1 per cent of the mutant alleles are beneficial. In view of the extremely low frequency of desirable mutations, spontaneous mutations cannot form the basis of a breeding programme. But spontaneous mutations are the source of all the genetic variations we see in the biological world today.

The ability of certain agents, called **mutagens,** to induce mutations at relatively very high rates has made mutations usable in plant breeding. Mutagens are of the following two types : (i) chemical and (ii) physical mutagens. **Chemical mutagens** are a variety of chemicals like ethylmethane sulphonate and sodium azide, that induce mutations. **Physical mutagens** are several kinds of radiation, e.g., X-rays, gamma-rays, ultraviolet rays etc., that cause mutation. These agents induce changes in DNA and chromosomes, which produce mutations. Mutations produced in response to a treatment with a mutagen are called **induced mutations**. **Mutation breeding** is the use of induced mutations in plant breeding to develop improved varieties.

Induced mutations generally produce only those alleles that are produced by spontaneous mutations. Their chief advantage, however, is the very high frequency at which they are obtained. In mutation breeding, usually seeds are treated with a suitable mutagen. The treated seeds are grown in the field and self-pollinated. Progeny from these plants are grown during the next crop season. These plants are carefully observed to identify and select mutations of interest. In the end, a desirable mutant line may be obtained which may be good enough to be released as a new variety. In India, over 200 varieties have been developed through mutation breeding. Induced mutations are useful in several specific situations, such as the lack of the desired alleles in the germplasm.

23.7 Polyploidy in Crop Improvement

Eukaryotic species are either diploid or polyploid. Somatic cells of a **diploid species/ individual** have two copies of a single genome. All the chromosomes belonging to a **genome** differ from each other in their gene contents, and often in morphology. The polyploid species/individuals are of the following two types : (i) autopolyploid, and (ii) allopolyploid. An **autopolyploid species/ individual** contains more than two copies of a single genome produced by itself. But **allopolyploid species/individuals** have two or more genomes derived from different

Monkombu Sambasivan Swaminathan

(1925-)

Born in August 1925 in Kumbakonam in Tamil Nadu, Swaminathan did his graduation and post-graduation in Botany from Madras University. He worked in different capacities in large number of institutions in India and abroad and developed his expertise in genetics and plant breeding.

School of Cytogenetics and Radiation Research established at Indian Agricultural Research Institute (IARI) enabled Swaminathan and his team to develop short duration high yielding varieties of rice including scented *Basmati*. He is also known for development of the concept of crop cafeteria, crop scheduling and genetically improving the yield and quality.

Swaminathan initiated collaboration with Dr. Borlaug, which culminated into the Green Revolution through introduction of Mexican varieties of wheat in India. This was rightly recognised and appreciated by Dr. Borlaug. He is also the initiator of *Lab to Land*, food security and several other environmental programmes. He has been honoured with several awards, medals and fellowships by institutions of excellence.

species/individuals, and each genome is ordinarily present in two copies.

Autopolyploidy

Autopolyploidy is produced spontaneously in nature in low frequency. It can be induced in relatively high frequencies by colchicine. **Colchicine** is an alkaloid that prevents the formation of spindle apparatus during mitosis. As a result, there is no anaphase movement of the chromotids, and all the chromatids of a dividing cell become included in the same nucleus. Consequently, the chromosome number of the cell is doubled. Autopolyploids have been produced in many crop species. They show increased plant size and vigour and produce larger leaves, fruits and flowers, but they also have many weaknesses. There are a few cases where an autopolyploid has succeeded as a variety, e.g., an autotriploid variety of tea in India. An autotriploid has three copies of a single genome.

Allopolyploidy

Allopolyploids are produced in two steps as follows. First of all, two different species are hybridised to produce an *F1*. The *F1* is usually highly sterile. Therefore, in the second step, the chromosome number of the *F1* is doubled. The resulting allopolyploid is usually at least partially fertile and forms a new species. Many allopolyploids have been produced in nature, some of which have succeeded as crops, e.g., wheat, oats, tobacco, etc. Humans have produced a new allopolyploid crop called *Triticale* in the following manner. Allotetraploid wheat (*Triticum turgidum*) was hybridised with rye (*Secale cereale*; a diploid species). The chromosome number of the resulting *F1* was doubled to produce triticale (Fig. 23.6). Triticale is cultivated in some areas of Punjab and in the hilly regions of the country.

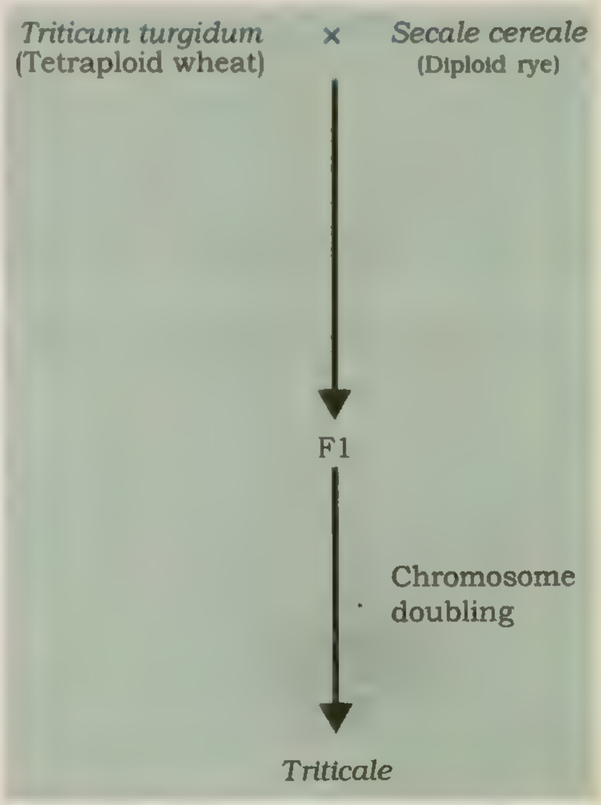


Fig. 23.6 *Production of Triticale from Triticum turgidum (tetraploid wheat) and Secale cereale (diploid rye)*

Haploidy

An individual/cell having the chromosome number found in the gametes of the species is called **haploid**. Therefore, a haploid has only one copy of each chromosome, and is highly sterile. When the chromosome number of a haploid plant is doubled, we obtain plants having the normal chromosome number for the species. These plants are homozygous for all their genes. Haploid plants are produced in nature at a low frequency, but in many species, they can be produced in high frequency by culturing their anthers/ovaries. Haploids are used for producing homozygous lines in about two years (see Chapter 24).

23.8 Breeding for Nutritional Quality

Quality of a crop-produce includes all those characters that determine its suitability for various uses. For example, fruit colour, size, shape, flavour, taste, etc. are important quality

characters in tomato, apple and other fruits. **Nutritional quality** of a crop refers to the suitability of its produce in human/animal nutrition. A crop-produce should provide the optimum nutrition and must not contain an antinutritional factor. **Antinutritional factors** are those compounds that have adverse effects on animal/human growth and development. Produces of certain crops contain antinutritional factors; for example, glucosinolates are present in the oils and cakes of rapeseed and mustard, and a neurotoxin is found in the seeds of 'khesari' (*Lathyrus sativus*). It is important that crop-produce be free from such antinutritional factors. In addition, the produce should contain adequate quality and quantities of proteins and oils.

As you know (Chapter 5), humans are unable to synthesise eight amino acids, which are called essential amino acids. Adequate amounts of these amino acids must be present in food. The contents of essential amino acids in proteins relative to the amounts needed in human diet constitute **protein quality**. Cereal and millet proteins are deficient in lysine and tryptophan, while those of pulses are deficient in sulphur containing amino acids, viz., methionine and cysteine. When a combination of pulses and cereals is consumed, all the essential amino acids are adequately supplied. Problem arises when the diet consists mainly of cereals and contains little or no pulses. Therefore, efforts have been focussed on developing lysine-rich varieties of cereals and millets. Three such varieties of maize, viz., 'Shakti', 'Rattan' and 'Protina', have been developed in India.

Human body requires fatty acids, which are provided by oil – the cooking medium in which most of our food is cooked. The various fatty acids present in oils are of two types : (i) saturated and (ii) unsaturated. The long chain saturated fatty acid and polyunsaturated fatty acid contents of various oils constitute **oil quality**. Long chain, saturated fatty acids, like erucic acid, are not good for human health. In contrast, polyunsaturated fatty acids are beneficial to human health. Therefore, efforts are made to develop such oilseed varieties that have higher levels of polyunsaturated fatty acids.

23.9 Breeding for Disease Resistance

Plants suffer from many diseases caused by pathogens like viruses, bacteria, fungi and nematodes. Table 23.1 includes examples of important diseases of crop plants. A **pathogen** is an organism that causes disease in another organism, which is called **host**. As shown in

Table 23.1 : Some Important Diseases of Crop Plants

Crop	Disease	Pathogen
	Diseases caused by Fungi	
Pigeon pea Potato	Fusarium wilt Late blight	*Fusarium udum* *Phytophthora infestans*
	Diseases caused by Bacteria	
Sugarcane Citrus	Red stripe/soft rot Canker	*Pseudomonas rubrilineans* *Xanthomonas citri*
	Diseases caused by Viruses	
Tobacco Tomato	Mosaic Mosaic	Tobacco mosaic virus (TMV) Tomato mosaic virus
	Diseases caused by Nematodes	
Tomato, Brinjal Wheat	Root-knot Earcockle/seed gall	*Meloidogyne incognita* *Anguina tritici*

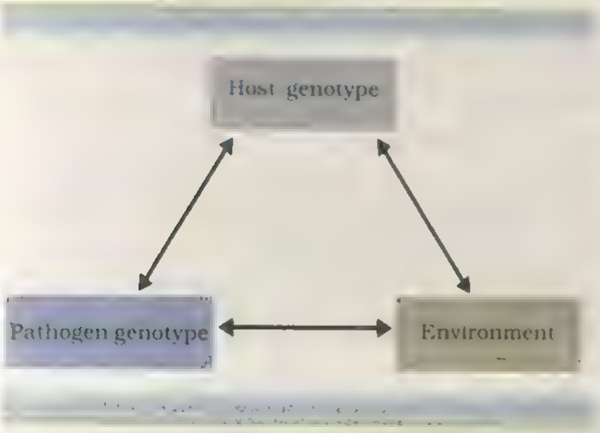


Fig. 23.7 *Development of disease depends on interactions among host genotype, pathogen genotype, and the environment*

Figure 23.7, the development of disease in a plant depends on the following factors : (i) host genotype, (ii) pathogen genotype, and (iii) the environment. We cannot exercise a control on pathogen genotype. In fact, pathogen genotype keeps on changing with time, and is a constant problem for breeders.

Some host genotypes possess the ability to prevent a pathogen strain from producing disease. Such host lines are called **resistant**, and this ability is called **resistance** or **disease resistance**. The term **strain** has a similar meaning for the pathogen as line has for the host. Those lines of a host that are not resistant to the pathogen are called **susceptible**. A successful breeding for disease resistance depends mainly on the following two factors : (i) a good source of resistance, and (ii) a dependable disease test. In **disease test**, all the plants are grown under conditions in which a susceptible plant is expected to develop disease. This allows a clear-cut identification of the disease-resistant plants, which are then selected.

Disease-resistant varieties provide the cheapest and a hazard-free means of controlling diseases. They are the only means for a predictable control of many diseases, e.g., wheat rusts, viral diseases, etc. In any case, such varieties are very important component of any package designed for disease control. Therefore, breeding for disease resistance is an integral part of every breeding programme. As a result, almost all modern-day varieties incorporate in them resistance for important diseases of the crop.

23.10 Animal Breeding

Animal breeding aims at improving the genotypes of animals to make them more useful to us. The chief objectives of animal breeding may be summarised as follows : (i) improved growth rate, (ii) increased production of milk, meat, egg, wool, etc., (iii) superior quality of milk, meat, eggs, wool, etc., (iv) improved resistance to various diseases, (v) increased productive life, and (vi) increased or, at least, acceptable reproduction rate, etc. A variety of strategies have been used for breeding of animals. The main approaches for animal breeding, viz., inbreeding, out-crossing and interspecific hybridisation, are briefly described below, based mainly on the breeding work with cattle.

Inbreeding

All domesticated animals have male and female individuals. As a result, they are strictly cross-fertilised, and highly heterozygous. Each domesticated animal species consists of several distinct breeds that differ from each other in several morphological and other features. You are familiar with the important breeds of cows, buffaloes, poultry, etc. Animals belonging to a single breed differ from each other in genotype because of the mode of their reproduction and their heterozygous nature. Therefore, mating between animals of the same breed provides opportunities for genetic improvement.

The breeding strategy based on inbreeding is as follows. Superior cows and superior bulls of the same breed are identified and mated in pairs. The progeny obtained from such matings are evaluated and superior males and females are identified for further mating. A **superior female,** in the case of cattle, is the cow that produces more milk per lactation. On the other hand, a **superior male** is that bull, which gives rise to superior progeny as compared to those of other males. Inbreeding, as a rule, increases homozygosity.

Inbreeding exposes harmful recessive genes that are eliminated by selection. It also helps in accumulation of superior genes and elimination of less desirable genes. Therefore, this approach increases the productivity of inbred population. Practically every breed was developed by some type of inbreeding. But continued inbreeding, especially close inbreeding, usually reduces fertility and even productivity (inbreeding depression). Whenever this becomes a problem, the selected animals of the breeding population should be mated with such superior animals of the same breed that are unrelated to those in the breeding population.

Cross-breeding

In this strategy, superior males of one breed are mated with superior females of another breed. Cross-breeding allows the desirable qualities of two different breeds to be combined in a single breed. The progeny animals may themselves be used as hybrids for commercial production. Alternatively, they may be subjected to some form of inbreeding and selection to develop new stable breeds that may be superior to the existing breeds. Many new animal breeds have been developed by this approach.

Progeny produced through cross-breeding may be mated according to various schemes to achieve specific objectives. For example, cows of an inferior breed may be mated to bulls of a superior breed. In each successive generation, the progeny cows are mated to the bulls of the same superior breed that was used in the original cross. Thus, in 6-7 generations, the progeny will be almost similar to the breed of bulls used for the mating. But these progeny would retain some useful features, e.g., adaptability to local conditions, etc., of the other breed from which the cows were used in the original mating.

Interspecific Hybridisation

In this strategy, male and female animals of two different species are mated. The progeny obtained from such a mating are usually different from both the parental species. In some cases, the progeny may combine desirable features of both the parents, and may be of considerable economic value. An example of this type is mule, which is produced from a cross between female horse (mare) and male donkey. Mules are sturdier and hardier than their parental species, and are well suited for hard work in difficult terrains like mountainous regions.

23.11 Hybrids

The best method of exploiting heterosis is to use the *F1* generation for commercial production. When *F1* seed from a cross is used for raising a commercial crop, the *F1* seed constitutes a **hybrid variety**. Hybrid varieties were first developed in maize, which is a cross-pollinated crop. In such crops, the parents of hybrid varieties are, ordinarily, inbred lines. An **inbred line** is a nearly homozygous line produced by continuous inbreeding in a cross-pollinated crop and is maintained by strict inbreeding. The different steps involved in development of a hybrid variety are as follows :

(i) production of inbred lines by continued inbreeding;
(ii) evaluation of inbred lines through a series of tests, and
(iii) large scale production of *F1* seed (hybrid seed) for distribution among farmers.

Hybrid varieties of many cross-pollinated crops, e.g., maize, sorghum, pearl millet, cotton, sunflower, etc., are in commercial use. More recently, hybrid varieties are becoming popular in self-pollinated crops like rice (Fig. 23.8) as well. In the case of self-pollinated

Fig. 23.8 *A hybrid variety (RH-10) of rice having long and scented grains* (Courtesy : Dr. A.K. Singh)

crops, pure lines are used as parents of the hybrid varieties. Further, hybrid seed production remains a problem in most self-pollinated crops.

Hybrids have long been used for commercial production in cattle, swine, sheep and poultry. Initially, crosses between breeds were used. Some hybrids of this type were better than their parents and other breeds, while others were not. In general, superior hybrids are likely to be obtained when genetically different parents are used in the cross. It was later recognised that the use of inbred stocks as parents gives predictable results. Further, often, even weak inbreds produce superior hybrids. Therefore, the modern practice of hybrid production is based on inbred stocks. Practically all hybrids of poultry and swine are produced by crossing inbred stocks.

23.12 Plant Diseases and their Control

In plants, **disease** may be defined as an abnormal development caused by either an abiotic or a biotic factor of the environment. Abiotic environmental factors like nutrient deficiencies, mineral toxicities, etc. can cause diseases in plants. Most plant diseases, however, are caused by various biotic environmental factors, called pathogens, namely, (a) viruses, (b) bacteria, (c) protozoa, (d) fungi, and (e) nematodes. In addition, some higher plants, like *Cuscuta* (a stem parasite) and *Striga* (a root parasite), may also cause disease. Different crops are attacked to different degrees by different pathogens.

Diseases reduce the total biomass produced by crops. This reduction may be the result of one or more of the following : (i) death of plants, (ii) killing of branches, (iii) damage to leaf tissues, (iv) general stunting, and (v) damage to reproductive organs, including fruits and seeds. Plant diseases (a) reduce the quantity and the quality of crop-produce, (b) may make the plant-produce poisonous to humans and animals, and (c) increase the cost of production.

The development of diseases and perpetuation of pathogens occur through a series of events, as follows : (i) The pathogen comes in contact with its host. (ii) It then enters into the host tissue through wounds, natural openings, or by direct penetration. (iii) The pathogen multiplies and spreads in the host tissues. (iv) Pathogen then reproduces, and the new individuals so produced spread to new host plants. (v) Finally, the pathogen must survive by some mechanism through that period of year when the host plants are absent, so that it is able to infect the host plants again during the next crop season.

Plant Diseases Caused by Fungi

All plants are attacked by fungal pathogens. Some parasitic fungi are **obligate parasites**, as they can grow and multiply only in association with their host plants. Other pathogenic fungi are **facultative parasites**, and they can grow and multiply on dead organic matter as well as on living host plants.

Dissemination : Fungi spread from plant to plant, and from one place to another, primarily in the form of spores. They are spread by wind, water, birds, insects, other animals and humans. Fungal pathogens enter their hosts by direct penetration through natural openings or through wounds.

Symptoms : The fungal pathogens produce either localised or general symptoms, like tissue death (necrosis) (Fig. 23.9),

Fig. 23.9 *Ascochyta leaf blight of chickpea caused by a fungus*

Table 23.2 : A Summary of the Important Common Symptoms of Plant Diseases caused by Fungi, Bacteria, Viruses and Nematodes

Symptom	Pathogen			
	Fungi	Bacteria	Viruses	Nematodes
Necrosis	+*	+	–	–
Excessive growth of tissues	+	+	–	–
Stunting	+	+	+	+
Pustules	+	–	–	–
Mosaics	–	–	+	–
Wilting	+	+	–	–
Pitting (Stem/Fruit)	–	–	+	–
Root galls	–	–	–	+
Excessive root branching	–	–	–	+

+ *, Common symptom; –, rare/absent symptom

stunting, etc. on their hosts. Some of the important symptoms produced by pathogens are summarised in Table 23.2.

Control of fungal diseases : A variety of measures are used to control fungal plant diseases. The important control measures are : use of resistant varieties, destruction of infected plant parts and crop residues, etc. (Table 23.3).

Plant Diseases caused by Bacteria

Bacteria are generally single-celled prokaryotes. Bacterial cells are enclosed by a cell membrane and a cell wall. Cell walls of most species are enveloped by a viscous gummy material. About 100 bacterial species cause plant diseases. Plant pathogenic bacteria develop mostly in host tissues. Populations of some pathogenic bacteria decline only gradually when they are released in soil. But some other pathogenic bacteria can survive as saprophytes only in the dead host tissue for varying durations.

Dissemination : Bacteria spread from plant to plant and to different parts of the same plant by water, insects, other animals and humans. Some bacteria persist in insects and depend on them for their survival and spread. Bacteria enter plants mainly through wounds and, sometimes, through natural openings.

Table 23.3 : A List of Some Important Control Measures for Plant Diseases caused by Fungi, Bacteria, Viruses and Nematodes

Control measure*	Pathogen			
	Fungi	Bacteria	Viruses	Nematodes
Resistant varieties	+*	+	+	+
Pathogen-free seed	+	+	+	+
Chemical	+	±	–	+
Biopesticides**	+	+	–	–
Control of insect vectors	–	–	+	–
Flooding of the field	–	–	–	+

* Control measure effective; ±, control measure moderately effective; –, control measure ineffective.
** For some plant diseases only.

Symptoms : Bacterial pathogens induce as many kinds of symptoms as do pathogenic fungi, *viz.*, necrosis, excessive growth of tissues, wilting etc. (Table 23.2, Fig. 23.10).

Fig. 23.10 *Bacterial blight of chickpea. The diseased plants are dead*

Control measures : Bacterial diseases are difficult to control, and often a combination of control measures is needed. The various control measures, like use of resistant varieties, use of healthy, disease-free seed, etc., are listed in Table 23.3.

Plant Diseases caused by Viruses

A **virus** is a nucleoprotein, in that it has a nucleic acid (DNA or RNA) genome surrounded by a protein coat. Viruses multiply only in living cells of their hosts. About 1/4th of all known viruses attack plants. Most plant viruses contain single-stranded RNA.

Dissemination : Viruses enter plant cells only through wounds either made mechanically (in some cases), or by vectors (in most cases). In almost all cases, viruses ultimately reach phloem, and are then transported to long distances within the plant. Spread of viruses from one plant to another occurs as follows : (i) through vegetative propagules, (ii) mechanically through sap of infected plants, (iii) through seed, (iv) through pollen, (v) by insect vectors, and (vi) by mites, nematodes and fungi.

Symptoms : The important symptoms produced by virus pathogens are stunting, and light green, yellow or white spots (mosaics) on leaves, flowers, fruits, or stem, etc. (Table 23.2, Fig. 23.11).

Fig. 23.11 *Increased proliferation in chickpea caused by cucumber mosaic virus*

Control measures : The various control measures for viral diseases are listed in Table 23.3. However, no chemical control is available for viral diseases.

Diseases caused by Nematodes

Nematodes are small animals that appear like worms, but are different from them. Many of them cause plant diseases. Plant parasitic nematodes lay eggs, which hatch into juveniles. All plant pathogenic nematodes spend part of their life in soil.

Dissemination : Nematodes are easily spread by water, animal feet, farm equipments, birds, humans and dust storms. In addition, they also move through the soil, but at a slow rate.

Symptoms : Nematodes feed on plants in the following way. They puncture cell wall, inject saliva into the cell and withdraw part of the cell contents. Most of the damage seems to be caused by the saliva injected into the cells. The different symptoms produced by pathogenic nematodes are root knots or root galls (Fig. 23.12), root lesions, excessive root branching, etc., and reduced growth of shoot, yellowing, etc. (Table 23.2).

Fig. 23.12 *Root knot of brinjal (eggplant) caused by a nematode (Courtesy : Prof. K.P. Singh)*

Control measures : The chief control measures for nematodes are listed in Table 23.3. Usually, a combination of these measures needs to be employed.

23.13 Animal Diseases and their Control

Domesticated animals suffer from a variety of diseases. In animals, **disease** may be defined as a state of discomfort associated with an abnormal function of the animal body. Diseases may be caused by mutant genes (**genetic diseases**), improper nutrition or pathogens. Genetic diseases are strictly selected against during animal breeding. Generally, animals are raised on properly balanced diets to avoid nutritional disorders and to ensure optimum performance. Domesticated animals suffer from diseases caused by (a) viruses, (b) bacteria, (c) protozoa, (d) fungi, and (e) animals, like worms. Such diseases are commonly known as **infectious diseases** because they are caused by pathogenic infections. Many of the infectious diseases are known as **contagious diseases** since they spread to healthy animals by contact with diseased animals, or with materials that were in direct contact with the diseased animals. Some of the infectious diseases may spread to humans from the animals, e.g., anthrax.

Infections can occur through skin, digestive tract, respiratory tract, conjunctiva, urogenital tract, placenta, umbilicus, breast feeding and egg. It is a good policy to implement measures for the prevention of infectious diseases, some of which are as follows :

(i) Isolation of animals suffering from or suspected to be infected with an infectious disease :
(ii) Proper disposal of the carcass and all materials that were in contact with the diseased animal(s).
(iii) Proper cleaning and disinfection of the animal house and other materials that were in contact with diseased animal(s).
(iv) Transfer of healthy animals to a pasture other than that used by diseased animal(s).
(v) Vaccination of animals.
(vi) Injection of antiserum into healthy animals whenever an epidemic is expected.
(vii) The authorities of the veterinary department should be immediately informed of cases of infectious diseases. This will allow them to initiate measures to prevent the spread of these diseases.

Bacterial Diseases

Animals suffer from several bacterial diseases. For example, cattle suffer from anthrax, mastitis, pneumonia, etc. Here, anthrax is discussed in some detail.

Anthrax : Anthrax is caused by the bacterium, *Bacillus anthracis*. This disease is contagious and affects cattle, horse, sheep and goats; it can also spread to human beings. In animals, anthrax spreads through contaminated feed, water and pastures.

Symptoms and diagnosis : In very acute cases, there is increased respiration, and blood-mixed foamy discharge from mouth, nose and anus. In such cases, the infected animals may die within minutes. But in sub-acute and chronic cases, the infected animals have high fever (up to 41.1°C), and increased pulse and respiration rates. There is discharge of black, shiny and foamy material from natural openings of animals. The infected animals die within 2 to 3 days. The anthrax bacterium uses up the oxygen carried by the animal blood. As a result, the animals die due to a lack of oxygen.

Disease diagnosis can be confirmed by microscopic observation of the bacterium in the blood of patients, or by culturing the bacterium present in the blood on a suitable medium.

Treatment : In the case of human beings, a suitable antibiotic like ciprofloxacin is quite effective, particularly if used in the initial stages of the disease. But in cattle, ciprofloxacin may be effective only in chronic cases. Anthrax antiserum can also be used with good results. In any case, antiserum should be given to all healthy animals to protect them from the disease.

Prevention and control : The general measures for prevention of infectious diseases should be followed. The healthy animals should be vaccinated. Animals that have come in contact with diseased animals should be given anthrax antiserum to protect them from the disease.

Viral Diseases

Animals suffer from a variety of viral diseases. For example, cattle suffer from rinderpest, foot and mouth disease, cowpox, etc. In this section, rinderpest is discussed in some detail.

Rinderpest : This disease is caused by a virus and is highly contagious. The virus is present in all the fluids and secretions from the body of diseased animals. The disease spreads rapidly by direct contact with patient animals, through contaminated feed, water, workers and their clothes, and by flies.

Symptoms : Initially, the infected animal develops fever (40.0 to 42.2°C), loses appetite, develops constipation, and passes hard faeces that often are covered with blood. In the final stages of the disease, animal suffers from loose motions, and gives off offensive odour. The body temperature declines and may go down below normal. The animal usually dies in about 7 days.

Treatment : Treatment is effective only when it is started in the initial stages of the disease. Injection of sulphamethazine sodium is often effective. Injection of rinderpest antiserum is highly effective, especially when combined with injection of sulphamethazine sodium.

Prevention : All the measures for prevention of infectious diseases should be implemented. It is highly desirable to vaccinate the animals against rinderpest. In 1954, a massive vaccination programme was initiated in India. This project has been highly successful, and rinderpest is no longer a dreaded disease.

Diseases caused by Parasitic Animals

Animals are attacked by a number of parasitic animals, e.g., tapeworm, round worms, flukes, ticks, etc. These parasites are mainly of two types : (i) ectoparasites, and (ii) endoparasites. **Ectoparasites** live on the skin, e.g., ticks, while **endoparasites** live within the animal body, e.g., round worm, tape worms, liver flukes, etc. Both types of parasites feed on animal fluids like blood, and interfere with their normal growth and development. Many parasites transmit pathogens and, thereby, help in the spread of the concerned diseases. Some of these parasites, e.g., tapeworm, also infect human beings.

Ascaris is an endoparasitic nematode that infects many animals, including humans. *Ascaris* larvae enter animal body through mouth along with contaminated feed. The larvae enter into the intestine tissue, and migrate to liver, lungs, spleen, pharynx, and kidneys, and re-enter the alimentary canal via oesophagus. They cause damage to all those organs through which they pass during their migratory phase. By the time the larvae reach intestine again, they develop into adult male and female individuals. The adult nematodes

cause wounds in the intestine and interfere with animal digestion. The affected animals may show symptoms like constipation, diarrhoea and anaemia. In severe cases, the animal may even die.

The female adult of *Ascaris* lays numerous eggs, which pass out along with the animal faeces. The eggs, in due course of time, hatch into larvae, which remain associated with grass. When cattle feed on the grass, the larvae enter alimentary canals of these animals.

Treatment : Treatment of *Ascaris* is based on administration of specific medicines, such as piperax, piperazine adipate, wormex, etc.

Diseases caused by Protozoa

Several diseases of animals are caused by protozoan parasites. Examples of such diseases are tick fever, coccidiosis, etc. We consider here tick fever in some detail.

Tick fever : This disease is caused by several species of *Babesia*, a protozoan parasite, which is spread by ticks. In India, tick fever is caused mainly by *Babesia bigemina*. The parasite enters into red blood cells (RBCs) and destroys them.

Symptoms : In the acute form of this disease, animals develop high fever (41.1-41.7°C) and stop feeding. But in the chronic form of tick fever, there is irregular fever, and constipation followed by diarrhoea. A clear diagnostic feature of the disease is the presence of pear-shaped protozoan parasite within the RBCs.

Treatment : The infected animals are administered a suitable medication, e.g., injection of trypan blue, acaprin, or berenil. A single injection of berenil is ordinarily sufficient to cure the animal. In addition, sanitation measures and a suitable insecticide treatment are implemented to eradicate the ticks.

Prevention and control : Tick fever can be prevented by effectively controlling the ticks. Insecticide treatments are used to eradicate ticks from animals and from pastures.

SUMMARY

Performance of an organism depends mainly on its genotype and the environment. Improvement in the genotype of a plant/animal to make it more suitable for humans is called breeding. Breeding begins after a species is domesticated, that is, a wild species is brought under human management. Plant breeding consists of the following activities : (i) creation of genetic variation, (ii) selection, (iii) evaluation and variety release, and (iv) seed multiplication and distribution.

Genetic variation can be created by (i) domestication, (ii) germplasm collection, (iii) plant introduction, (iv) hybridisation, (v) polyploidy, (vi) mutation, and (vii) genetic engineering. Of these, hybridisation is the most commonly used method. Selection aims at the isolation of the best pure line in the case of self-pollinated crops. But in cross-pollinated crops, the objective of selection is to increase the frequency of superior genotypes without reducing heterozygosity. The lines developed by selection are evaluated at several locations for 4-5 years before they are released as a variety. The seeds of improved varieties are multiplied and supplied to farmers.

The basis of a successful breeding programme is a good germplasm collection, i.e., a collection of different lines of a crop and its wild relatives. Germplasm can also be imported. In such cases, strict quarantine is necessary to prevent the entry of weeds, insects and pathogens. Mating between individuals related by descent (inbreeding) leads to a loss in vigour and fertility (inbreeding depression). This is common in cross-pollinated

crops, but is not observed in self-pollinated crops. Mating between unrelated parents often produces *F1* superior to both the parents (heterosis). Heterosis is observed in all species. It is exploited by hybrid breeds of animals and hybrid varieties of crops. The most likely reason for inbreeding depression is the deleterious effects of recessive alleles that become homozygous due to inbreeding. Similarly, heterosis results when the harmful effects of recessive alleles present in one parent are hidden by the dominant alleles of the same genes present in the other parent and *vice-versa*. Heterosis is best utilised when *F1* generation is used for commercial production.

Certain chemical and physical agents can induce mutations in a high frequency. Use of these mutations in breeding has given us over 200 crop varieties (in India). Autopolyploidy can be induced by colchicine; it has yielded few successful varieties. Allopolyploidy has been more successfully utilised in breeding. A new crop, called triticale, has been produced by crossing wheat with rye and doubling the chromosome number of the resulting *F1* hybrid. Haploids are used for rapid production of homozygous lines through doubling of their chromosome numbers. Breeding has been successful in removing some anti-nutritional factors, and in modifying protein and oil contents and qualities. Certain crop genotypes are able to resist certain pathogens. Efforts to develop disease-resistant varieties have been very successful. In fact, breeding for disease resistance is one of the major activities in case of most crop species.

Animal breeding aims at improving animal genotypes so that they become more useful to humans. All the animal breeds were developed by some form of inbreeding. Inbreeding increases homozygosity, helps eliminate harmful alleles and improves performance. But continued inbreeding reduces fertility, and often performance (inbreeding depression). In such cases, mating with unrelated animals of the same breed or of a different breed should be used. The progeny from mating between different breeds may be used for commercial production, or for further breeding to develop new breeds. Interspecific crosses can also be used to produce useful new animals like mule.

Both plants and animals are attacked by a variety of diseases caused by viruses, bacteria, protozoa, fungi, nematodes, etc. Effective measures have to be implemented for controlling these diseases so that the losses caused by them are kept to a minimum. In plants, development of disease-resistant varieties is the most effective and dependable strategy. But for animals, vaccination (where available) is highly effective. In addition, proper sanitation measures minimise the risk of disease epidemics.

EXERCISES

A. Pick the correct option from among those provided.

1. Which of the following is most commonly used for creation of genetic variation?
   (a) Polyploidy
   (b) Hybridisation
   (c) Mutation
   (d) Genetic engineering

2. Which of the following is the consequence of plant diseases?
   (a) Reduced yield and lower quality of produce
   (b) Reduced yield, lower quality of produce and increased cost of production
   (c) Reduced yield, lower quality of produce and poisonous produce
   (d) Reduced yield, lower quality of produce, increased cost of production and poisonous produce.

3. The use of colchicines is involved in production of
   (a) somaclonal variation
   (b) haploids
   (c) polyploids
   (d) hybrids

4. Viruses enter into their host through
   (a) wounds made by insect vectors
   (b) natural openings
   (c) direct penetration
   (d) wounds made mechanically or by insect vectors

5. Which of the following **is not** correct about plant introductions?
   (a) They give us new crops
   (b) They give us new varieties
   (c) There is a risk of entry of disease, etc. into the country
   (d) Quarantine is not necessary.

6. Which of the following animal diseases is caused by a virus?
   (a) Anthrax
   (b) Rinderpest
   (c) Tick fever
   (d) Coccidiosis

7. Mule is produced by
   (a) selection.
   (b) inbreeding.
   (c) interspecific hybridisation.
   (d) cross-breeding.

8. Which of the following category of plant diseases cannot be controlled by chemical treatment?
   (a) Viral diseases
   (b) Diseases caused by nematodes
   (c) Fungal diseases
   (d) Both (a) and (b)

9. Hybrids are produced by crossing inbreds in which of the following?
   (a) Maize
   (b) Poultry
   (c) Swine
   (d) All of these

10. Some types of lines/events are listed in column I, while column II lists the manner in which they can be obtained. Match the items in columns I and II.

Column I	**Column II**
(i) Hybrid variety	(a) X- rays
(ii) Mutation	(b) Allopolyploidy
(iii) Pure lines	(c) *F1* generation
(iv) Triticale	(d) Selection in self-pollinated crops
	(e) Genetic engineering

11. Define the following terms :
    (a) Hybridisation
    (b) Genetic engineering
    (c) Interspecific hybridisation
    (d) Inbreeding
    (e) Inbreeding depression
    (f) Quarantine
    (g) Autopolyploidy
    (h) Pathogen
    (i) Disease resistance
    (j) Allopolyploidy
12. Explain the following in not more than 100 words each and discuss their importance for human welfare.
    (a) Disease control in plants
    (b) Hybridisation
    (c) Improved seed
    (d) Germplasm
    (e) Plant introduction
    (f) Heterosis
    (g) Mutation
    (h) Polyploidy
    (i) Nutritional quality
    (j) Disease resistant varieties
13. Briefly describe the various steps involved in the development of improved varieties of crops.
14. Discuss the role of plant breeding in enhancing food production.
15. Explain the meanings and the bases of heterosis and inbreeding depression. Discuss their importance for increased food production.
16. Briefly describe the various types of plant diseases and the measures for their control.
17. Briefly describe important animal diseases and the measures for their control.
18. Discuss the relevance of animal breeding to improved food production.
19. What are hybrids? Briefly describe their production and importance in boosting animal and crop productions.

Chapter 24

Plant Tissue Culture and Biotechnology

Humans have consistently tried to improve domesticated animals and plants to make them more useful. You have seen in the previous chapter that this consists primarily of two basic steps, viz., creation of genetic variation and selection of the desired genotypes. Genetic variation is created by recombining alleles of the different genes present in the genome of organisms. Therefore, humans have constantly searched for alleles and genes of interest. Until recently, genes could be transferred only by sexual means, i.e., by hybridisation. However, all breeding and seed multiplication activities had to be carried out in the field. But during the later half of the twentieth century, several new techniques were developed, which allow the use of genes from any source. However, they are dependent on specialised laboratory facilities and technical skill. You have already studied about recombinant DNA technology, animal cloning and DNA fingerprinting. In this chapter, we shall consider various aspects of plant tissue culture, and some applications of recombinant DNA technology. In addition, we shall learn about Genetically modified food, Biofertilisers, Biopesticides, Single cell protein, Biopatent, Biopiracy, Biowar and Bioethics.

24.1 Plant Tissue Culture

Plant tissue culture is the maintenance and growth of plant cells, tissues and organs on a suitable culture medium *in vitro* (in a container, e.g., test tube). Plant tissue cultures are often classified according to the type of *in vitro* growth, viz., callus and suspension cultures [Fig. 24.1(a)], or the explant used for culture initiation, *e.g.*, embryo culture, anther culture, etc. [Fig. 24.1(b)]. An **explant** is the plant part that is excised from its original location and used for initiating a culture (Fig 24.2). It is essential that the explants, culture vessels, media and the instruments used for plant tissue culture be made free from microbes. The explants are, therefore, treated with specific anti-microbial chemicals. The vessels, media and instruments are also suitably treated with steam, dry heat or alcohol, or subjected to filtration to make them free from microbes; this is called **surface sterilisation**. Surface sterilisation of explants and their transfer to culture media must be done under aseptic conditions.

Culture medium provides the nutrition that is required for the desired growth and development of the explants. Standard media are available for most purposes. These media contain inorganic salts, some vitamins, sucrose (as a source of carbon and energy) and the desired growth regulators. The growth regulators commonly used in plant tissue culture are auxins like IAA, NAA, 2,4-D (2,4-dichlorophenoxyacetic acid) and cytokinins, such as kinetin BAP (benzylaminopurine). Growth regulators are required for cell division and organ differentiation from the cultures. The cultures are usually kept in a culture room at about 24°C with some illumination.

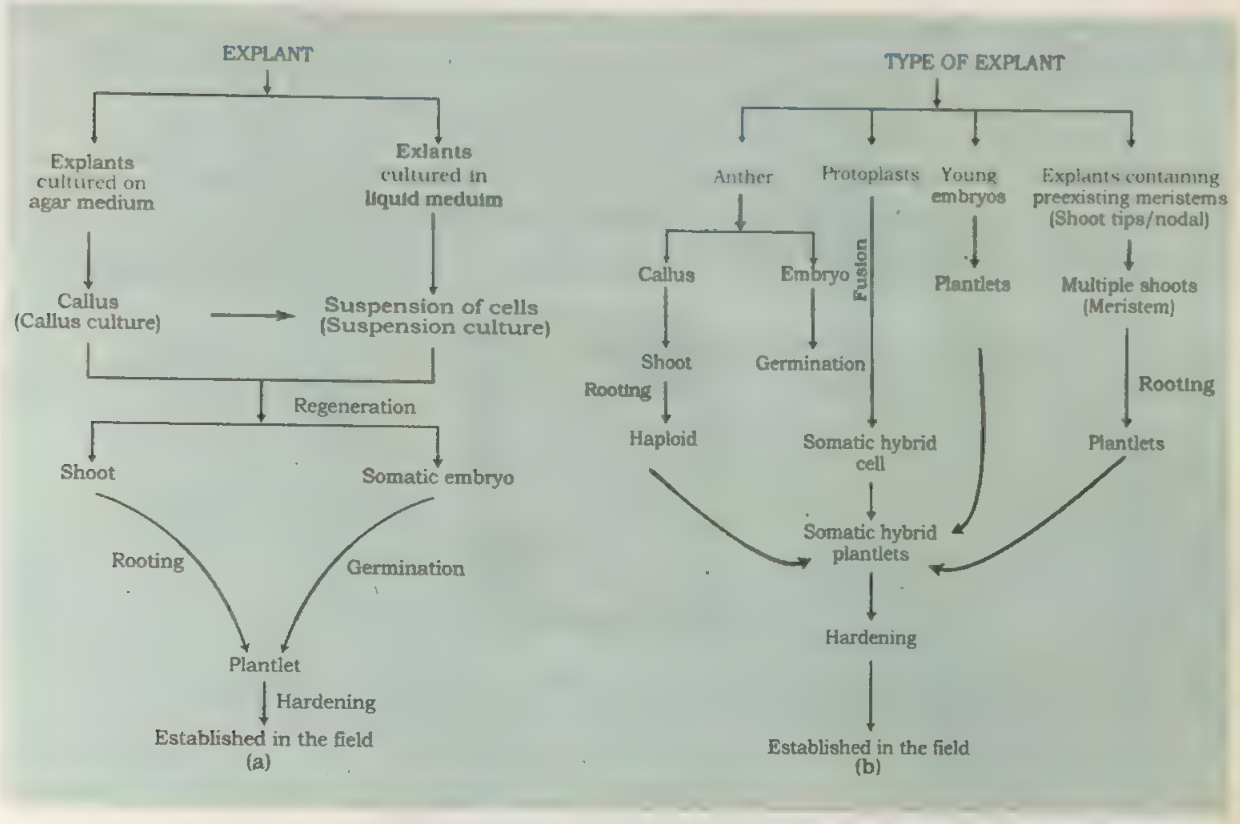


Fig. 24.1 *A flow-chart showing the various types of plant tissue culture and recovery of complete plants from them : (a) callus and suspension cultures, (b) anther, protoplast, embryo and shoot tips*

Callus and Suspension Cultures

In **callus cultures**, cell division in the explant leads to formation of a callus mass, which is an unorganised mass of cells. It is maintained usually on a medium gelled with agar. The medium ordinarily contains an auxin and often a cytokinin also. When an explant is placed on such a medium, many of the cells become meristematic and begin to divide. In about 2-3 weeks, a callus mass is obtained. In contrast, a **suspension culture** consists of single cells and small groups of cells suspended in a liquid medium (Fig. 24.2). Usually, the medium contains the auxin 2,4-D. Suspension cultures must be constantly agitated at 100-250 rpm (revolutions per minute). Agitation serves the following three purposes : (a) aeration of culture, (b) constant mixing of the medium, and (c) breakage of cell aggregates into smaller cell groups. Suspension cultures grow much faster than callus cultures.

With passage of time, the following three things happen in all types of plant tissue cultures : (i) cell/tissue dry matter (biomass) increases, (ii) the level of nutrients in the medium decreases, and (iii) the medium volume declines due to evaporation. Therefore, if tissue cultures were kept in the same culture vessel, they will die in due course of time. In view of this, cells/tissues are regularly transferred into new culture vessels containing fresh media.

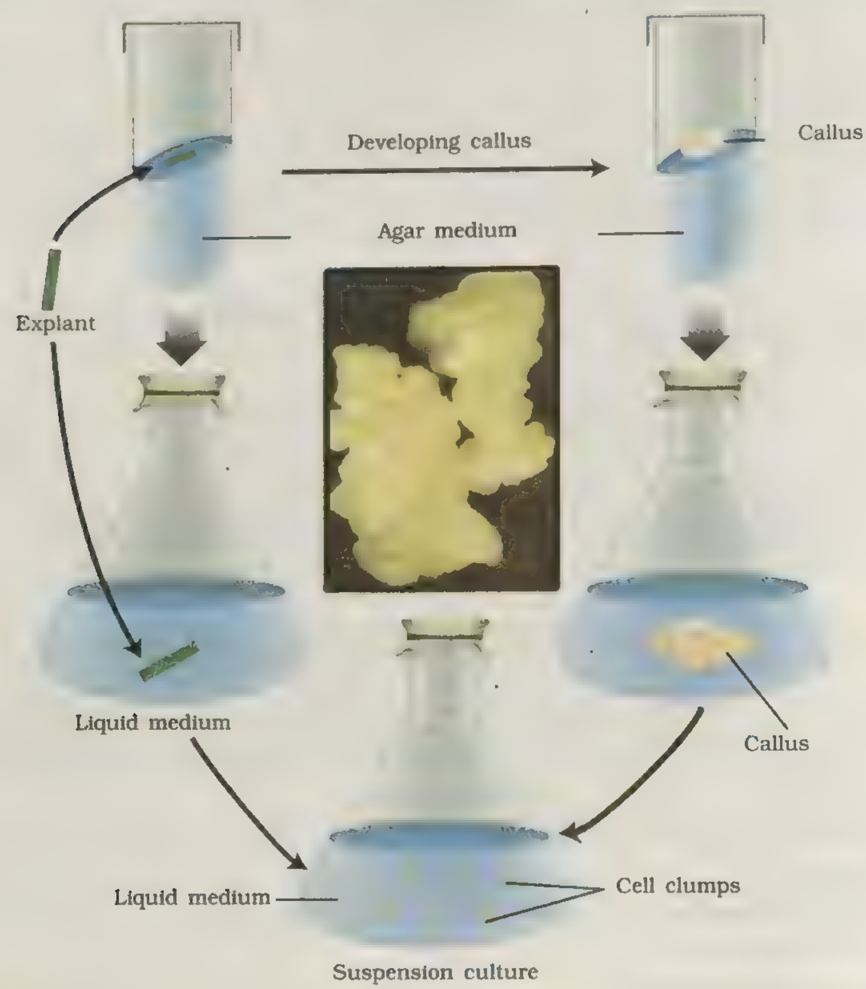


Fig. 24.2 *Initiation of callus and suspension cultures*

This process is called **subculturing** (Fig. 24.3). It may be pointed out that during subculture, only a part of the culture is transferred into the new culture medium.

The callus and suspension cultures can be used to achieve cell biomass, regeneration of plantlets, production of transgenic plants and isolation of protoplasts; most of these you will study later in this chapter.

Regeneration of Plantlets

Plant cells cultured *in vitro* can ultimately give rise to complete plants. The ability of plant cells to regenerate into complete plants is called **totipotency**. In fact, Gottlieb Haberlandt started the technique of plant tissue culture in 1902, when he attempted to culture isolated single cells from leaf mesophyll to determine if these were totipotent. Plantlets can be

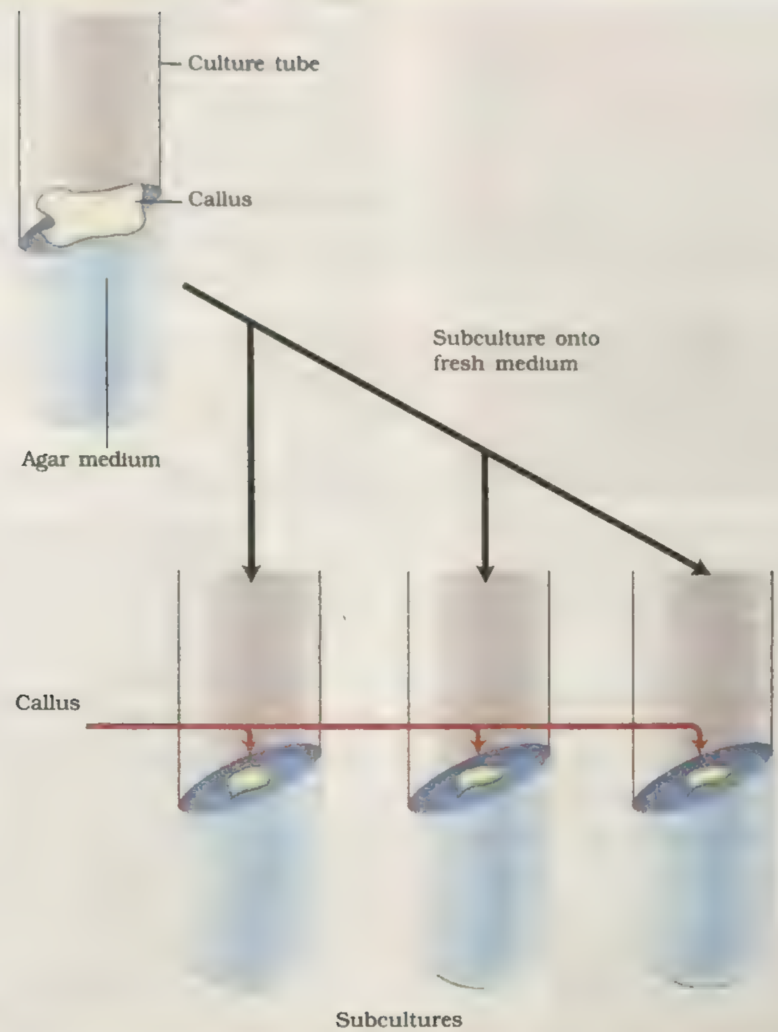


Fig. 24.3 *Schematic representation of subculturing*

obtained from cultured cells by two different routes : (i) shoot regeneration followed by rooting of the shoots (organogenesis), and (ii) regeneration of somatic embryos (somatic embryogenesis) followed by their germination. **Regeneration** describes the development of an organised structure, like root, shoot or somatic embryo from cultured cells.

Root and Shoot regeneration : Shoot regeneration is promoted by cytokinins like BAP. In contrast, root regeneration is promoted by auxins like NAA (naphthalene acetic acid). In fact, shoot and root regeneration is generally controlled by the auxin-cytokinin balance. An excess of the auxin promotes root regeneration, whereas that of cytokinin promotes shoot regeneration. Callus cultures are first kept on a cytokinin containing medium. After some time, shoots regenerate from callus cells. When the shoots become 2-3 cm long, they are excised and transferred to an auxin-containing medium. Roots regenerate from the lower ends of these shoots to yield complete plantlets.

Fig. 24.4 *Somatic embryo regeneration from callus culture*

Somatic embryo regeneration : A somatic embryo develops from a somatic cell (Fig. 24.4). The pattern of development of a somatic embryo is comparable to that of a zygotic embryo in development and function.

Fig. 24.5 *Complete plantlets produced by somatic embryo germination*

Somatic embryo regeneration is induced usually by a relatively high concentration of an auxin, such as 2,4-D. These young embryos develop into mature embryos either on the same medium or on another medium. Mature somatic embryos germinate to yield complete plantlets (Fig. 24.5).

Establishment in the field : The plantlets can be removed from culture vessels and established in the field (Fig. 24.6). This transfer is done following specific procedures called **hardening.** During hardening, plantlets are kept under reduced light and high humidity for a suitable period of time. Hardening procedures make the plantlets capable of tolerating the relatively harsher environments outside the culture vessels.

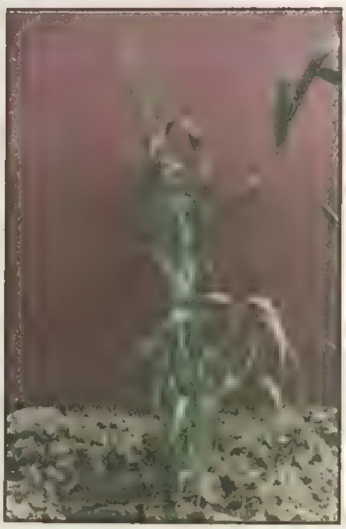


Fig. 24.6 *A wheat plant bearing fertile spikes. This plant is one of those that had developed from the plantlets transferred from the culture tube to the field.* (Courtesy : Dr. B. Arun)

Meristem Culture

We have considered in the previous subsection *de novo* (afresh) regeneration of shoots from cultured plant cells. Alternatively, one can use an explant that contains

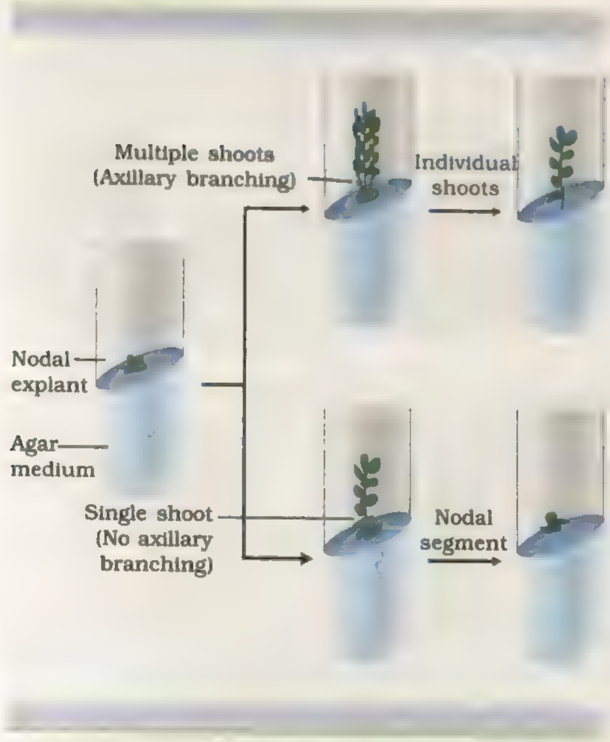


Fig. 24.7 *Micropropagation by stimulation of axillary buds to develop into shoots*

pre-existing shoot meristems and produce shoots from them. Such cultures are called **meristem culture**. The explants commonly used in meristem culture are shoot tips and, more often, nodal segments (axillary meristems). These explants are cultured on a medium containing a cytokinin (usually BAP). Cytokinins promote axillary branching by overcoming apical dominance. Therefore, they support multiple shoot development from each explant (Fig. 24.7). When axillary branching takes place, individual shoots are cultured. But when axillary branching does not take place, the single shoot is cut into nodal segments, which are then cultured again. Shoots of 2-3 cm are excised and rooted on a suitable medium. The plantlets thus obtained are subjected to hardening and ultimately, established in the field. Meristem cultures can be used for rapid clonal multiplication, and production of virus-free plants. They are also useful in germplasm conservation and production of transgenic plants.

Embryo Culture

Excision of young embryos from developing seeds and their cultivation on a nutrient medium is called **embryo culture**. In general, older embryos are more easily cultured *in vitro* than young embryos. The objective of embryo culture is to allow the young embryos to complete development and, ultimately, give rise to seedlings. Embryo culture has following applications :

(i) In some interspecific crosses, the endosperm of developing hybrid seeds degenerates at an early stage. Since young embryos obtain nutrition from endosperm, the young hybrid embryos also die when the endosperm degenerates. Therefore, such interspecific crosses cannot be normally made. In such cases, young hybrid embryos are rescued by excision and cultured *in vitro* to obtain hybrid seedlings. This technique is also known as **embryo rescue** technique. Several interspecific hybrids have been produced in this way.

(ii) Seeds of some plants, like orchids, lack stored food. Embryo culture in such cases allows seedling development from most of the embryos.

(iii) In some species, seeds may remain dormant due to inhibitors present in the endosperm/seed coat. Embryo culture in such cases allows the embryos to develop into seedlings by eliminating the inhibitors and overcoming dormancy.

Anther Culture and Haploid Production

Haploids are produced in many plant species when their anthers are cultured on a suitable medium. This is called **anther culture**. This technique was first used in India to produce haploids of *Datura*. Following anther culture, the nucleus within a pollen grain may continue to divide and give rise to a pollen embryo by adventive embryogeny. Alternatively, the continued division in pollen produces a callus, which then regenerates shoots. In several species, the pollen grains can be isolated and

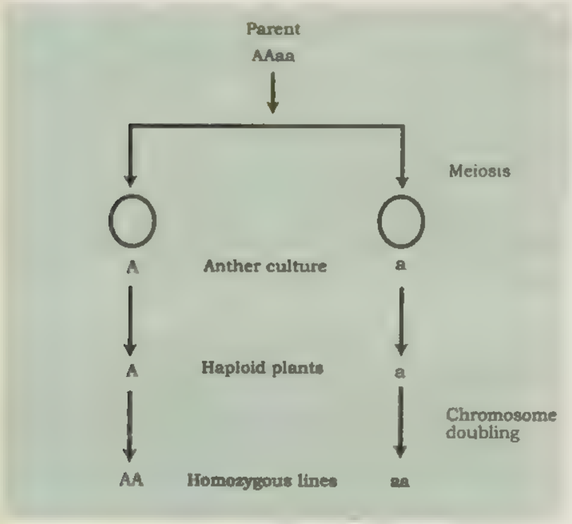


Fig. 24.8 *Production of homozygous lines using anther culture. The two parents are shown to differ for only one gene, i.e., AA and aa.*

cultured to obtain haploids. In many plant species, haploids can also be produced by culturing unfertilised ovaries/ovules.

Haploids are completely sterile and of no direct value. But they are important since they are used to produce homozygous lines (Fig. 24.8). This strategy can be easily integrated into breeding programmes. Anthers from *F1* plants (obtained by crossing two or more lines) are cultured to obtain haploid plants. The chromosome number of these haploid plants is doubled by using colchicine to obtain homozygous plants. The progeny from these plants are then subjected to selection to isolate superior homozygous lines. This approach has been successfully used to develop several varieties.

Protoplast Culture and Somatic Hybridisation

A hybrid produced by fusion of somatic cells of two varieties or species is called **somatic hybrid**. The process of producing somatic hybrids is known as **somatic hybridisation** (Fig. 24.9). The first step in somatic hybridisation is the removal of cell wall by

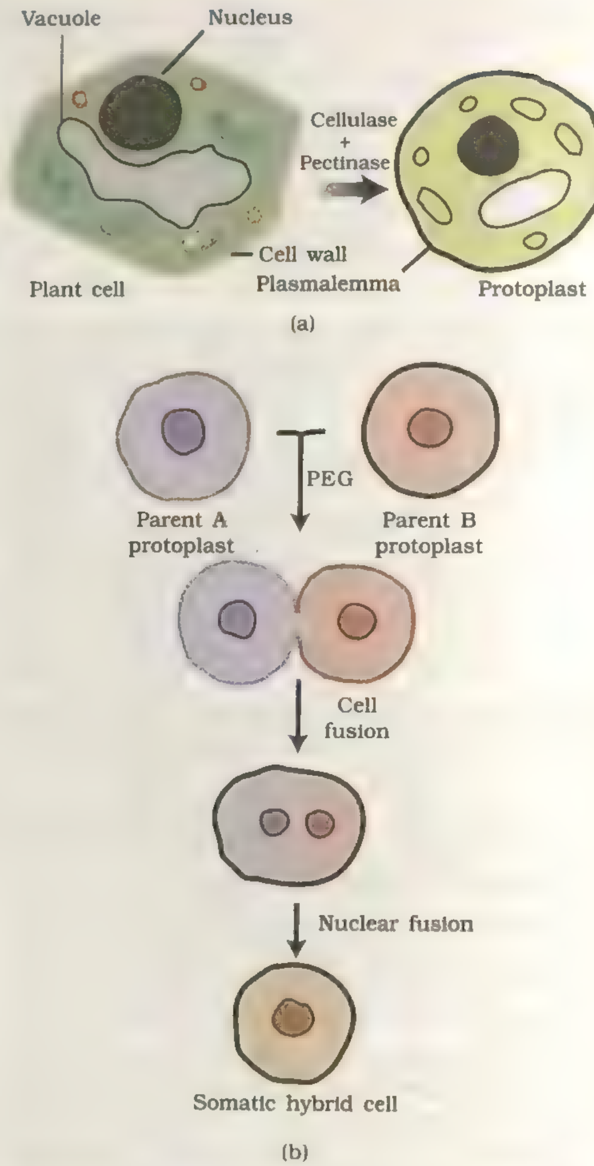


Fig. 24.9 *Somatic hybridisation. (a) Production of protoplasts using a combination of pectinase and cellulase. (b) Protoplast fusion induced by PEG ultimately yields somatic hybrids*

digestion with a combination of pectinase and cellulase. The plant cells lacking cell wall are called **protoplasts** [Fig. 24.9(a)]. Fusion between protoplasts of the selected parents is

induced by a solution of polyethylene glycol (PEG), or by a very brief high voltage electric current [Fig. 24.9(b)].This leads to the formation of a hybrid cell. When the protoplasts are cultured on a suitable medium, they regenerate cell walls and begin to divide to ultimately produce plantlets. Somatic hybrids can be identified by using several approaches.

Somatic hybridisation allows the production of hybrids between lines and species, that cannot be produced normally by means of sexual hybridisation. For example, the somatic hybrid between a non-flowering clone of potato and a flowering potato clone produced fertile flowers. Similarly, somatic hybrids were produced between rice and carrot. In both these cases, sexual hybrids cannot be produced. Somatic hybrids may be used for gene transfer, transfer of cytoplasm and production of useful allopolyploids.

Applications : Practical applications of plant tissue culture are mainly based on the ability of plant cells to give rise to complete plantlets. The use of plant cells to generate useful products and/or services constitutes **plant biotechnology**. In most plant biotechnology activities, the useful product is a plantlet that, in many cases, may have been genetically altered. These plantlets have been used for the following purposes :

(i) *Rapid Clonal Propagation* : A **clone** is a group of individuals or cells derived from a single parent individual or cell through asexual reproduction. All the cells in callus or suspension culture are derived from a single explant by mitotic division. Therefore, all plantlets regenerated from a callus/suspension culture generally have the same genotype and constitute a clone. These plantlets can be used for rapid clonal propagation of superior lines. This has been done in some plant species, like oil palm.

(ii) *Disease* - free plants via meristem culture.

(iii) Embryo rescue for viable hybrids.

(iv) Haploid Plants by anther culture.

(v) Somatic hybrids by protoplant fusion.

(vi) *Transgenic Plants* : A gene that is transfered into an organism by genetic engineering is called **transgene**. An organism that contains and expresses a transgene is known as **transgenic organism**. You will recall that transgenes can be introduced into individual plant cells. The cells containing and expressing transgenes can be easily selected *in vitro*. Ultimately, plantlets can be regenerated from these cells. These plantlets give rise to the highly valuable transgenic plants (see Section 24.4).

24.2 Biotechnology

Biotechnology may be defined as the use of microorganisms, animal or plant cells, or their components to generate products and services useful to human beings.

Humans have been using micro organisms for thousands of years to obtain products like curd, wine , vinegar, bread, etc. But they did not know that micro-organisms were involved in these processes. Micro-organisms were first used to produce some organic compounds like citric acid, following the First World War. Subsequently, micro-organisms were employed to generate a variety of products, including antibiotics. In addition, animal and plant cells cultured *in vitro* are used to obtain several valuable products (Table 24.1). In all these processes, only the natural capabilities of the organisms and cells are exploited. In several instances, genetic improvements have enhanced the levels of production. For example, penicillin yield has been improved by a factor of about 1,000. But the types of products obtained have remained the same, as those obtained from the natural strains/cell lines.

During 1970's, the technique of recombinant DNA technology was developed. Genetic engineering is a popular term for recombinant DNA technology. Recombinant DNA techniques permit the isolation of desired gene from any organism, and its transfer and expression into the organism of choice.

Transgenic micro-organisms are produced with a view to obtain novel pharmaceutical proteins. For example, human insulin is being commercially produced from a transgenic *Escherichia coli* strain that contains and expresses the human insulin gene. Such

Table 24.1 : Some Important Applications of Micro-organisms, Animal Cells and Plant Cells in Agriculture, Industry and Human Health

Organism/cell	Applications	
	Agriculture	**Industry and human health**
	Non-transgenic Strains/Lines	
Micro-organisms	Biofertiliser Bioinsecticide'	Vaccine production Antibiotic production Vitamins Organic compounds Single cell protein
Animal cells	–	Vaccine production Animal proteins (including antibodies)
Plant cells, tissues and organs	Micropropagation Haploid plants Somatic hybrids Somaclonal variants	Secondary metabolites including pharmaceutical compounds Micropropagation
	*Transgenic Strains/Lines**	
Micro-organisms	–	Novel pharmaceutical proteins Vaccines, New products
Animal cells	–	New pharmaceutical proteins Vaccines, Antibodies
Plant cells	Transgenic crops with resistance to herbicides, insects, viruses; modified quality; improved nutrition	New pharmaceutical proteins New high value products Genetically modified food

* These products are not made by the natural strains/lines of the concerned organisms. In many cases, the products could never be produced on a commercial scale from non-transgenic cells or organisms.

proteins produced by transgenes (expressed in transgenic cells/organisms) are called **recombinant proteins**. Many valuable recombinant proteins are also being produced, using transgenic animal cell lines and transgenic plants (Table 24.1).

24.3 Genetically Modified Crops

A **transgenic crop** is a crop that contains and expresses a specific transgene. A popular term for transgenic crops is **genetically modified crops** or **GM crops**. The techniques used for the production of transgenic crops offer the following two unique advantages : (i) any gene (from any organism or a gene synthesised chemically) can be used for transfer, and (ii) the change in genotype can be precisely controlled since only the transgene is added into the crop genome.

In contrast, conventional plant breeding activities

(i) can use only those genes that are present in such species that can be hybridised with them. In addition,
(ii) changes occur in all those traits for which the parents used in hybridisation differ from each other.

When a transgene is introduced into the genome of an organism, it can achieve one of the following :

(i) produces a protein that is the product in which we are interested.

(ii) produces a protein that on its own produces the desired phenotype,
(iii) modifies an existing biosynthetic pathway so that a new end-product is obtained,
(iv) prevents the expression of an existing native gene.

We shall briefly examine some of these achievements. **Hirudin** is a protein that prevents blood clotting. The gene encoding hirudin was chemically synthesised. This gene was then transferred into *Brassica napus*, where hirudin accumulates in the seeds. The hirudin is purified and used for medicinal purpose (Fig. 24.10). In this case, the transgene product itself is the product of interest.

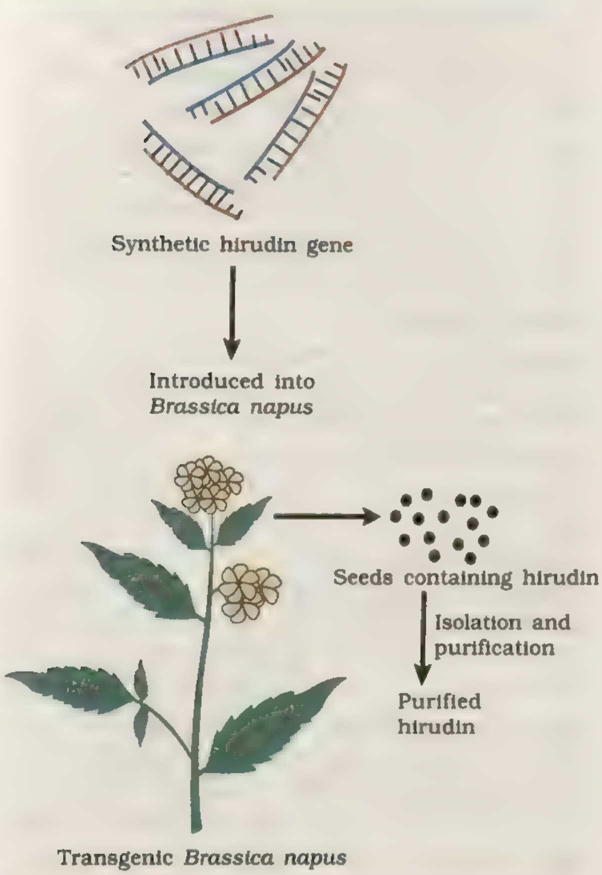


Fig. 24.10 *A simplified representation of the production of hirudin from transgenic Brassica napus seeds*

A soil bacterium, *Bacillus thuringiensis (Bt)*, produces a crystal (Cry) protein. The Cry protein is toxic to larvae of certain insects. The gene encoding Cry protein, viz., *cry* gene, has been isolated and transferred into several crops. A crop expressing a *cry* gene is usually resistant to the group of insects for which the concerned Cry protein is toxic. This is a case where the transgene product directly produces the phenotype of interest.

The tomato variety 'FlavrSavr' presents an example where expression of a native tomato gene has been blocked. Expression of a native gene can be stopped by many different methods. Fruit softening is promoted by the enzyme polygalacturonase, which degrades pectin. Production of polygalacturonase was blocked in the transgenic tomato variety 'FlavrSavr'. Therefore, fruits of this tomato variety remain fresh and retain their flavour much longer than do the fruits of normal tomato varieties. In addition, the fruits have a superior taste and increased total soluble solids; these are unexpected bonus.

GM crops are already in cultivation in U.S.A., Europe and several other countries. In India, some insect resistant cotton varieties expressing *cry* genes have reached the farmers' fields. It has been however argued that transgenic crops may be harmful to the environment.

24.4 Genetically Modified Food

The food prepared from the produce of genetically modified (= transgenic) crops is called **genetically modified food** or, in short, **GM food.** GM food differs from the food prepared from the produce of conventionally developed varieties mainly in the following aspects. Firstly, it contains the protein produced by the transgene in question, e.g., Cry protein in the case of insect resistant varieties. Secondly, it contains the enzyme produced by the antibiotic resistance gene that was used during gene transfer by genetic engineering. Finally, it contains the antibiotic resistance gene itself.

It has been argued that the above features of GM foods could lead to the following problems when they are consumed. Firstly, the transgene product may cause toxicity and/or produce allergies. Secondly, the enzyme produced by the antibiotic resistance gene could cause allergies, since it is a foreign protein. Finally, the bacteria present in the alimentary canal of the humans could take up the antibiotic resistance gene that is present in the GM food. These bacteria would then become resistant to the concerned antibiotic. As a result, these bacteria could become difficult to manage.

The scientists involved in the production of transgenic crops are addressing to these concerns. Efforts are being made to use other genes in place of antibiotic resistance genes. The toxic and allergenic actions of the transgene product can be adequately examined by detailed assays using suitable animal models.

24.5 Sustainable Agriculture

Modern agricultural practices utilise non-renewable resources and cause pollution. These practices cannot be continued indefinitely, i.e., are not sustainable. Sustainable development reduces the use of non-renewable resources, as well as the level of pollution. **Sustainable agriculture** would primarily use renewable resources, and cause the minimum pollution and maintain the optimum yield level. Biotechnology can contribute to sustainable agriculture in several ways; some of these are briefly discussed below.

Biofertilisers

Micro-organisms employed to enhance the availability of nutrients like nitrogen (N), and phosphorus (P) to crops are called **biofertilisers.** You know that several micro-organisms fix atmospheric nitrogen and make them available to plants. Examples of nitrogen-fixing micro-organisms are bacteria and cyanobacteria (blue-green algae); some of these are free-living, while others form symbiotic association with plant roots. **Rhizobia** form root nodules in legume crops and some cyanobacteria form symbiotic association with the fern *Azolla*.

Insoluble forms of soil phosphorus are converted into soluble forms by certain micro-organisms. This makes the phosphorus available to the plants. Phosphate is solubilised by some bacteria and by some fungi that form association with plant roots. The fungus and plant root association is called **mycorrhiza.** Some of these fungi are present on root surface only, whereas others enter into the roots as well. These fungi solubilise phosphorus, produce plant growth promoting substances and protect host plants from soil pathogens. Several other micro-organisms used as biofertiliser promote plant growth and protect plants from soil pathogens.

Biofertilisers are a low-cost input and they do not pollute the environment. They also reduce the dependence on chemical fertilisers. However, the acceptability of biofertilisers has been rather low. This is because they usually do not produce quick and spectacular results. However, extensive efforts are being made to enhance the effectiveness and the contribution of biofertilisers for agricultural production.

Biopesticides

Biopesticides are those biological agents that are used for control of weeds, insects and pathogens. The micro-organisms used as biopesticides include viruses, bacteria, fungi, protozoa and mites. Some of the biopesticides are being used even at a commercial scale.

Insects are attacked by many micro-organisms as well as mites. One example is the soil bacterium, *Bacillus thuringiensis*. Spores of this bacterium produce the insecticidal Cry protein. Therefore, spores of this bacterium kill larvae of certain insects (see Section 24.4). The commercial preparations of *B. thuringiensis* contain a mixture of spores, Cry protein and an inert carrier. This bacterium was the first biopesticide to be used on a commercial scale in the world, and is also the first such product to be produced at commercial scale in India. Certain bacteria and fungi are also being used for control of some weeds and diseases in various crops. The use of biopesticides is expected to reduce

the dependence on chemicals for control of diseases, insect pests and weeds. These chemicals are a source of widespread pollution. In addition, the presence of their residues in agricultural products is a health hazard to humans.

Disease and Insect-resistant Varieties

Genetic engineering has enabled the development of crop varieties resistant to certain insects and diseases. Production of insect-resistant varieties was considered in the preceding section. Production of disease resistant varieties is briefly described here. Plant diseases are caused by viruses, bacteria, fungi and nematodes.

The most successful approach for the production of virus resistant plants is the transfer of the virus coat protein gene into the plants.Viruses have a simple organisation. Their genetic material is enclosed in a protein coat. The gene encoding coat protein is isolated from the genome of the virus that causes the concerned disease. This gene is then transferred and expressed in the host of the concerned virus. Expression of the coat protein produces resistance in the host to this virus. This approach has been used to produce virus-resistant variety of plants. Efforts are also being made to produce varieties resistant to diseases caused by bacteria and fungi using different approaches. Development of disease and insect-resistant varieties is expected to minimise the use of chemicals for their control and, as a result, pollution. In addition, such varieties will reduce yield losses due to insects and diseases and, thereby, enhance agricultural production.

Single Cell Protein

Micro-organisms have been widely used over ages for preparation of a variety of fermented foods, e.g., cheese, butter, *idlis*, etc. In addition, some microorganisms have been used as human food, e.g., the blue-green alga, *Spirulina*, and the fungi commonly known as mushrooms. More recently, efforts have been made to produce microbial biomass using low-cost substrates and use it for human consumption or as feed. Cells from a variety of microorganisms, viz., bacteria, yeasts, filamentous fungi and algae, treated in various ways and used as food or feed are called **single cell protein (SCP)**. The term SCP, however, is misleading since the biomass is obtained from both mono-and multi-cellular micro-organisms.

The substrates used for SCP production range from CO_2 (used by algae) through industry effluents like whey, etc. to low-cost organic materials like saw dust and paddy straw. Commercial production of SCP is mostly based on yeasts and some other fungi, e.g., *Fusarium graminearum*. In most cases, SCP has to be processed to remove the excess of nucleic acids. SCP is rich in high quality protein and is rather poor in fats. Both these features are desirable in human food.

SCP provides a valuable protein-rich supplement in human diet. Their use should help bridge the gap between the requirement and the supply of proteins in the human diet. It should also reduce the pressure on agricultural production systems for the supply of the required proteins. In addition, SCP production based on industrial effluents helps reduce environmental pollution.

24.6 Biopatent

A **patent** is the right granted by a government to an inventor to prevent others from commercially using his invention. A patent is granted for (a) an invention (including a product), (b) an improvement in an earlier invention, (c) the process of generating a product, and (d) a concept or design. Initially, patents were granted for industrial inventions, etc. But at present, patents are being granted for biological entities and for products derived from them; these patents are called **biopatents**. Primarily, industrialised countries, like U.S.A., Japan and members of European Union, are awarding Biopatents.

Biopatents are awarded for the following : (i) strains of microorganisms, (ii) cell lines, (iii) genetically modified strains of plants and animals, (iv) various biotechnological procedures, (v) production processes, (vi) products, and (vii) product applications.

There has been a great deal of opposition from various social groups to the patenting of life forms. The nature of these objections is mainly ethical and political. The arguments in favour of biopatents are primarily of increased economic growth.

24.7 Biopiracy

Many organisations and multinational companies exploit and/or patent biological resources or bioresources of other nations without proper authorisation from the countries concerned; this is known as **biopiracy.** The industrialised nations are rich in technology and financial resources but poor in biodiversity and traditional knowledge related to the utilisation of the bioresources. In contrast, developing nations are poor in technology and financial resources, but are rich in biodiversity and traditional knowledge related to bioresources.

Biological resources or **bioresources** include all those organisms that can be used to derive commercial benefits. **Traditional knowledge related to bioresources** is the knowledge developed by various communities over long periods of history, regarding the utilisation of the bioresources, *e.g.*, use of herbs, etc. as drugs. Often, this traditional knowledge can be exploited to develop modern commercial processes. The traditional knowledge suggests the direction to be followed, and saves considerable time, effort and expenditure for their commercialisation. Institutions and companies of industrialised nations are collecting and exploiting the bioresources, as follows.

(i) They are collecting and patenting the genetic resources themselves. For example, a patent granted in U.S.A covers the entire 'basmati' rice germplasm indigenous to our country.

(ii) The bioresources are being analysed for identification of valuable biomolecules, a compound produced by a living organism. The biomolecules are then patented and used for commercial activities.

(iii) Useful genes are isolated from the bioresources and patented. These genes are then used to generate commercial products.

(iv) The traditional knowledge related to bioresources is utilised to achieve the above objectives. In some cases, the traditional knowledge itself may be the subject of a patent.

A west African plant, *Pentadiplandra brazzeana* produces a protein called **brazzein**, which is approximately 2,000 times as sweet as sugar. In addition, brazzein is a low-calorie sweetener. Local people have known and used the super-sweet berries of this plant for centuries. But the protein brazzein was patented in U.S.A. Subsequently, the gene encoding brazzein was also isolated, sequenced and patented in U.S.A.

24.8 Biowar

Biowar or **Biological war** is the use of biological weapons against humans and, or their crops

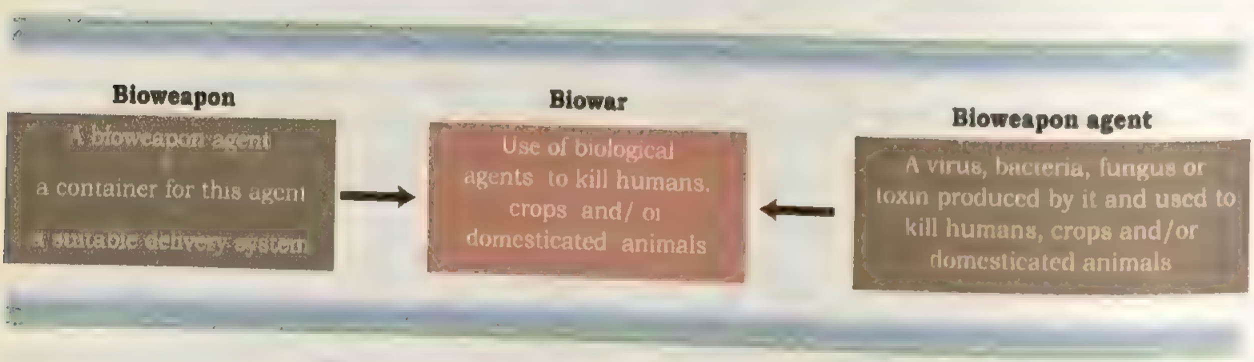


Fig. 24.11 The meaning of biowar and its tools

and animals. A **biological weapon** or **bioweapon** is a device that carries and delivers to the target organism a pathological biological agent or a toxin derived from it. The biological agent/toxin, called **bioweapon agent**, is kept in a suitable container so that it remains active and virulent during delivery (Fig. 24.11). This container could be delivered in various ways, including missiles and aircraft. The use of biological agents in war may date back to 5th century B.C.

Some of the potential pathogens for bioweapons are those that cause anthrax, small pox, etc., and the botulinum toxin. Some of these agents have already been used, e.g., the *Anthrax* bacterium sent through letters after September 2001. Mass-produced pathogens or their toxins are delivered either as powder or in the form of spray, using a variety of delivery devices. Bioweapons (a) are low-cost weapons, (b) cause far more casualties than chemical or conventional weapons, and (c) bioweapon agents are invisible, and extremely difficult to detect. These features make bioweapon agents very convenient for use by terrorists and even governments, and both have used them on a limited scale.

The possible defences against bioweapons include the use of respirator or gas mask, vaccination, administration of appropriate antibiotics, and decontamination. In addition, sensitive detection systems should be developed to control and minimise damage.

24.9 Bioethics

Ethics includes a set of standards by which a community regulates its behaviour and decides as to which activity is legitimate and which is not. Therefore, **bioethics** may be viewed as a set of standards that may be used to regulate our activities in relation to the biological world. Biotechnology, particularly recombinant DNA technology, is focussed on exploiting the biological world in ways that are usually unprecedented. Therefore, biotechnology connotations ranges from 'unnatural' to 'detrimental' to 'biodiversity'. The major bioethical concerns pertaining to biotechnology are summarised below.

(i) Use of animals in biotechnology causes great suffering to them.

(ii) When animals are used for production of pharmaceutical proteins, they are virtually reduced to the status of a 'factory'.

(iii) Introduction of a transgene from one species into another species violates the 'integrity of species'.

(iv) Transfer of human genes into animals (and *vice-versa*) dilutes the concept of 'humanness'.

(v) Biotechnology is disrespectful to living beings, and only exploits them for the benefit of human beings.

(vi) Biotechnology may pose unforeseen risks to the environment, including risk to biodiversity.

SUMMARY

Biotechnology generates useful products and services by using microorganisms, plant and animal cells and their components. Recombinant DNA technology is used to produce transgenic organisms that possess novel capabilities. Plant cells and organs can be cultured *in vitro* on a suitable medium; this is known as tissue culture. The explants, media, vessels and instruments used in tissue culture must be made free from microbes. Culture of explants on an agar medium containing auxin yields callus cultures. Cells can also be grown in a liquid medium as a suspension of single cells and cell groups. A constant agitation of suspension cultures is essential. Complete plantlets can be obtained from agar and suspension

cultures either through organogenesis, or somatic embryogenesis. These regenerated plantlets can be transferred and established in the field.

Shoot-tip and node explants can be cultured to produce large number of plants. Young embryos can be cultured to obtain plants, particularly from interspecific crosses. Haploid plants can be obtained from anther and ovary cultures. Chromosome numbers of haploid plants can be doubled to produce homozygous lines within only 2-3 years. Cell walls can be digested, using a combination of pectinase and cellulase. The resulting protoplasts can be fused to produce somatic hybrids.

Plant tissue cultures have several potential and realised applications. One of its most important applications is production of transgenic crops. A transgenic crop contains one or more genes transferred by genetic engineering. Transgenic crops resistant to insects, with changed quality, capable of producing a medicinal protein, etc., are already being cultivated. Food obtained from transgenic crops is called genetically modified food. Concerns have been expressed that such foods may be toxic, may cause allergies, and may affect microbial populations of the alimentary canal. Efforts are being made to adequately address these concerns.

Sustainable agriculture should use renewable resources, should not cause pollution and should maintain optimum yields. Biotechnology contributes to sustainable agriculture by developing biofertilisers, biopesticides, disease- and insect-resistant varieties and single-cell proteins. Biofertilisers are microorganisms that make available to plants either atmospheric nitrogen or soil phosphorus. Biopesticides consist of viruses, bacteria, protozoa, fungi or mites that help control diseases, insects or weeds. The use of biofertilisers, biopesticides, and disease- and insect-resistant varieties helps save non-renewable resources and reduces pollution. Single-cell protein is microbial biomass rich in high quality protein. These serve as valuable food and feed supplements.

Developments in biotechnology have accelerated biopatenting and biopiracy. Biopatents are patents granted for biological entities and processes. Biopiracy is unauthorised use of bioresources and traditional knowledge related to bioresources for commercial benefits. These developments favour rich industrialised nations of the north, at the cost of developing nations of south. Another risk arises from the use of disease-causing organisms like viruses, bacteria and fungi to destroy crops, domesticated animals and human populations (biowar). Developments in biotechnology have raised several bioethical issues. Each society has to evaluate these issues and take appropriate decision about them.

EXERCISES

Pick the correct option from among those provided.

1. Biopiracy is related to which of the following?
   (a) Traditional knowledge
   (b) Biomolecules and regarding bioresources, genes isolated from bioresources
   (c) Bioresources
   (d) All of the above

2. Which of the following is used in biowar?
   (a) A pathogen
   (b) Toxin from a pathogen
   (c) A delivery system for the bioweapon agent
   (d) All of the above.
3. Which of the following is included in biopesticide?
   (a) Viruses and bacteria.
   (b) Viruses, bacteria and fungi.
   (c) Viruses, bacteria, fungi, protozoa and mites.
   (d) Viruses, bacteria, fungi and protozoa.
4. Which of the following can be controlled by using biopesticides?
   (a) Insects
   (b) Diseases
   (c) Weeds
   (d) All of them.
5. Biofertilisers include :
   (a) Blue-green algae, rhizobia, other nitrogen-fixing bacteria and mycorrhiza fungi.
   (b) Blue-green algae, rhizobia and other nitrogen-fixing bacteria.
   (c) Rhizobia, other nitrogen-fixing bacteria and mycorrhiza fungi.
   (d) Blue-green algae, rhizobia and mycorrhiza fungi.
6. Which of the following combinations of risk are associated with genetically modified food?
   I. Toxicity
   II. Allergic reaction
   III. Antibiotic resistance in micro-organisms present in alimentary canal.

   Options:

   (a) I and II

   (b) I, II and III

   (c) I and III

   (d) II and III
7. Embryo culture is used for :
   (a) establishing suspension culture.
   (b) recovery of interspecific hybrids.
   (c) somatic hybridisation.
   (d) haploid production.
8. A transgene expression can achieve which of the following?
   (a) Prevent expression of a native gene.
   (b) Modify an existing biosynthetic pathway.
   (c) Produce a protein that itself produces the phenotype of interest, or is the product of interest.
   (d) All of the above.
9. Match the objects given in column I with the products listed in column II.

Column I	Column II
(i) 2,4-D	(a) Virus resistance
(ii) Coat protein gene	(b) Somatic hybridisation
(iii) PEG	(c) Callus culture
(iv) *Cry* gene	(d) Insect resistance
	(e) Haploid plants

10. Define the following terms :
    (a) Surface sterilisation
    (b) Subculture
    (c) Somatic embryo
    (d) Protoplast
    (e) Somatic hybrid
    (f) Biotechnology
    (g) Transgene
    (h) Transgenic organism
    (i) Sustainable agriculture
    (j) Sterilisation.
11. Explain the meaning of the following and their relevance to human welfare in not more than 100 words :
    (a) Callus and suspension cultures
    (b) Meristem culture
    (c) Embryo culture
    (d) Anther culture
    (e) Somatic hybridisation
    (f) Totipotency
    (g) Biofertilisers
    (h) Biopesticides
12. Explain the following terms in not more than 70 words :
    (a) Single-cell proteins
    (b) Biopatent
    (c) Biowar
    (d) Bioethics
    (e) Biopiracy
    (f) Genetically modified food
13. Discuss the role of plant tissue culture in increasing food production.
14. Elaborate as to how biotechnology can be helpful in achieving sustainable agriculture.
15. Bring out the salient features through which biotechnology can lead to higher food production.
16. 'Biotechnology can greatly promote human welfare, but it can also be misused to increase human sufferings'. Comment on the statement with the help of suitable examples.

Chapter 25

Immune System and Human Health

We are continually exposed to various foreign particles, including infectious agents like bacteria, viruses, protozoa and other parasites. It has long been noticed that survivors of certain diseases, e.g., measles, are not attacked by the same disease again. Clearly, these people have become immune to the concerned disease. The system of our body, which protects us from various infectious agents is called **immune system**. A study of the immune system is known as **immunology**. The objective of this chapter is to introduce the fundamental concepts of immune system and their use for the improvement of human health and welfare.

Innate and Acquired Immunity

The Latin term "Immunis", meaning "exempt" or "freedom", gave rise to the English word immunity. It refers to all the mechanisms used by the body for protection from environmental agents that are foreign to the body. These agents may be microorganisms or their products, certain food items, chemicals, drugs and pollen, etc. Immunity is of two types : (a) **innate**, and (b) **acquired** immunity.

25.1 Innate Immunity

Innate immunity comprises all those defense elements with which an individual is born, and which are always available to protect a living body. One strategy of innate immunity consists of various types of barriers that prevent entry of foreign agents into the body. Even when pathogens enter into the body, they are quickly killed by some other components of this system. This is the first line of defence of most animals. Innate immunity consists of the following four types of barriers : (a) anatomical, (b) physiological, (c) phagocytic, and (d) inflammatory barriers.

Anatomic Barriers

These barriers block the entry of organisms into the body. They consist of skin and the mucous membranes. Mucous entraps foreign micro-organisms and cilia propel micro-organisms out of the body.

Physiological Barriers

Factors like body temperature, pH and various body secretions, prevent growth of many pathogenic micro-organisms. For example, fever response inhibits growth of many pathogens. Acidity of the stomach contents kills most ingested micro-organisms. Lysozyme present in secretions, such as tears, digests bacterial cell walls, and interferon induces antiviral state in non-infected cells. Certain kinds of cells, when infected with a virus, respond by releasing a small amount of a class of glycoproteins, called **interferons**. Interferons, in turn, protect the cells in the vicinity resistant to viral infections. This involves several mechanisms, such as synthesis of antiviral proteins. As a result, the concerned persons exhibit increased resistance to viral infections.

Phagocytic Barriers

Phagocytosis is an important mechanism of innate immunity. In response to pathogenic infections, the total count of leucocytes increases sharply. Humans contain wandering phagocytes

Fig. 25.1 *A phagocyte with bacteria attached to its surface*

Fig. 25.2 *A natural killer cell (small one) attacking a tumour cell*

(Fig. 25.1), that circulate through the body. The most important phagocytes are the macrophages and the neutrophils. **Macrophages** (big eaters) are large irregular-shaped cells that engulf microbes, viruses, cellular debris, etc. In response to an infection, **monocytes** are liberated at the site of infection, and become converted into macrophages.

Inflammatory Barriers

You might have noticed that an infection or tissue injury often results in redness and swelling, along with pain and production of heat that may result in fever. Such manifestation is localised and is known as **inflammatory response**. This response occurs due to release of chemical alarm signals, notably histamine and prostaglandins, by the damaged mast cells. There is a leakage of vascular fluid, which contains serum proteins with antibacterial activity. Further, there is an influx of phagocytic cells into the affected area. These responses inhibit and destroy the invading microorganism (Fig. 25.1).

Besides the phagocytes, **natural killer cells** kill virus-infected cells and some tumour cells of the body by creating perforin-lined pores in the plasma membrane of the target cells (Fig. 25.2). These pores allow entry of water into the target cell, which then swells and bursts.

Complement system participates in both innate and acquired immunities. It consists of over 30 proteins that act in various ways to protect the individual from foreign invaders. The member proteins of the complement system function in an orderly manner. Ultimately, there is formation of transmembrane pores in the microbes, which leads to their lysis (Fig. 25.3). Some components

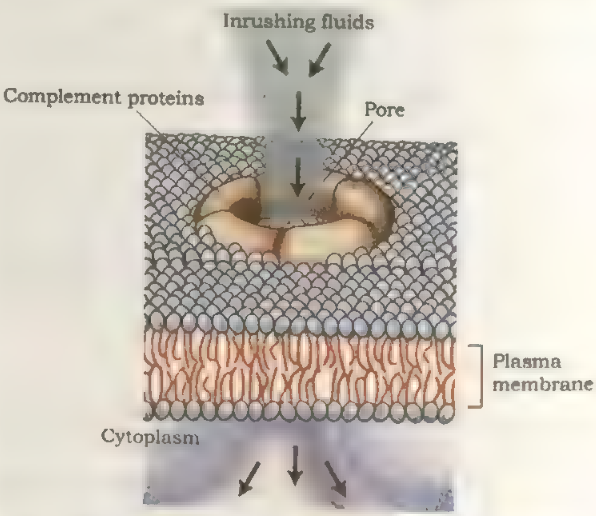


Fig. 25.3 *Complement proteins creating a hole in the plasma membrane*

of the complement system coat the invading microbes. This coating enables phagocytes to readily attach to the microbes and destroy them.

25.2 Acquired Immunity

Acquired immunity, also known as **adaptive** or **specific immunity**, is capable of recognising and selectively eliminating specific microorganisms. Acquired immunity is found only in vertebrates. It supplements the protection provided by innate immunity. It is generated in response to an exposure to the microorganisms in question. Specific defence mechanisms require several days to be activated, following the breach of non-specific defence mechanisms. Adaptive immunity has the following unique features :

(i) ***Specificity*** : It is the ability to distinguish differences among various foreign molecules.

(ii) ***Diversity*** : It can recognise a vast variety of foreign molecules.

(iii) ***Discrimination between Self and Non-self*** : It is able to recognise and respond to molecules that are foreign or non-self. At the same time, it can avoid response to those molecules that are present within the body (self) of the given animal.

(iv) ***Memory*** : When the immune system encounters a specific foreign agent, e.g., a microbe, for the first time, it generates immune response and eliminates the invader. The immune system retains the memory of this encounter. As a result, a second encounter with the same microbe evokes a heightened immune response.

Specific immunity employs two major groups of cells : (a) lymphocytes, and (b) antigen presenting cells. A healthy human being possesses about a trillion **lymphocytes**. The lymphocytes are of two types, viz., **T lymphocytes** or **T cells** and **B lymphocytes** or **B cells.** Both the types of lymphocytes, as well as the other cells of the immune response, are produced in **bone marrow**; the process of their production is called **haematopoiesis.** Some immature lymphocytes, destined to become thymocytes, migrate via the blood to the **thymus**, where they mature as T cells. The B cells, on the other hand, divide and mature in the bone marrow itself. The B and T cells, together, generate the following two types of specific immunity : (a) cell-mediated immunity (by T cells), and (b) antibody-mediated or humoral immunity (by B cells).

The large and complex foreign molecules (mainly proteins) that activate the specific immunity are known as **antigens.** Our immune system can recognise a vast variety of antigens readily. **Antigenic determinants** are those sites on antigens that are recognised by antibodies and receptors present on T and B cells. An antigen triggers a specific immune response against itself.

Adaptive immunity may be active or passive. **Active immunity** is due to the immune response generated in the individual in question by a pathogen or vaccine, whereas **passive immunity** is conferred by transfer of immune products, like antibodies, etc., from another individual into a non-immune individual.

Activation of Adaptive Immunity

Every antigen is processed by antigen presenting cells like macrophages, B lymphocytes, etc. The processed antigen is presented on the surface of these cells. A subgroup of T cells called **T helper cells**, specifically interacts with the presented antigen and becomes activated. The activated T helper cells then activate B cells, and a subgroup of T cells called **T cytotoxic cells**, in a specific manner. The activated B cells and T cytotoxic cells proliferate to produce clones. All the cells of a clone recognise the same antigen and eliminate it.

Cell-mediated Immunity

Cell-mediated immunity is the responsibility of a subgroup of T cells, called T cytotoxic cells. An activated T cytotoxic cell is specific to a target cell which has been infected, and kill the target cell by a variety of mechanisms. This prevents the completion of life cycle of the pathogen, since it depends on an intact host cell. Cell-mediated immunity is also involved in killing of cancer cells.

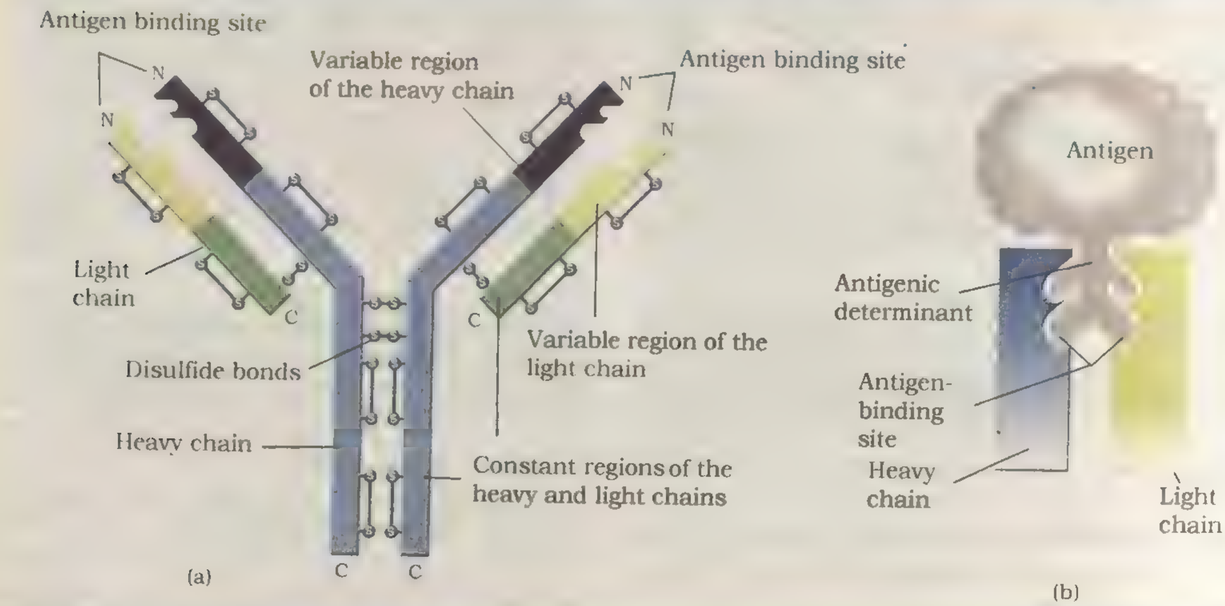


Fig. 25.4 *Immunoglobulins : (a) Structure, (b) Antigen binding site*

Antibody-mediated Immunity

The B cells produce specialised glycoproteins called **antibodies**. These glycoproteins are highly specific to specific antigens. Antibodies are collectively termed as **immunoglobulins** or **Ig** (Fig. 25.4). Each immunoglobulin molecule is made up of 4 polypeptide chains. There are two long chains, called **heavy** or **H chains**, and two short chains, called **light** or **L chains**. The four polypeptide chains are held together to form a Y-shaped molecule. The top two tips of this Y-shaped molecule bind to the specific antigens in a lock-and-key fashion, forming an **antigen-antibody complex**. Each antigen has many different antigenic determinants, each of which matches a specific antibody and binds to it (Fig. 25.5). The B cells, thus, direct the **antibody-mediated immunity** (also called **humoral immunity**).

The antibody molecules may be bound to a cell membrane or they may remain free. The free antibodies have three main functions: **agglutination** of particulate matter, including bacteria and viruses, **opsonisation** or coating of bacteria to facilitate their subsequent phagocytosis by cells, and **neutralisation** of toxins released by bacteria, e.g., tetanus toxin. In humans, immunoglobulins are grouped into the following five classes : IgA, IgD, IgE, IgG

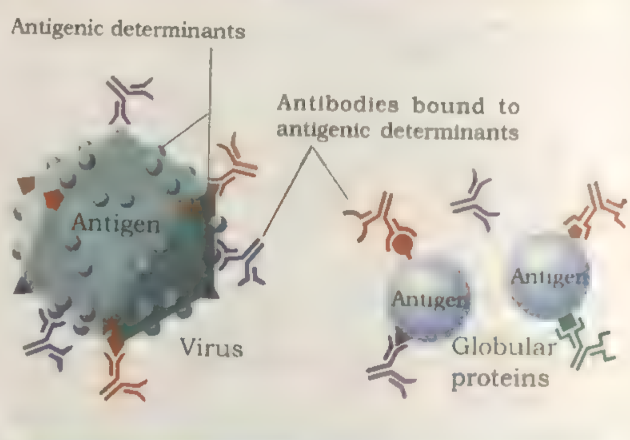


Fig. 25.5 *Formation of antigen-antibody complex*

Table 25.1 : Functions of Different Immunoglobulin Classes

Immunoglobulin Class	Function
IgA	Protection from inhaled and ingested pathogens.
IgD	Present on lymphocyte surface as receptors, activation of B cells.
IgE	Mediator in allergic response.
IgG*	Stimulation of phagocytes and complement system passive immunity to foetus.
IgM	Activation of B cells.

*Most abundant Ig (about 75 per cent of human antibodies); only antibody that can cross placenta.

and IgM. The functions of these immunoglobulins are listed in Table 25.1.

25.3 Clonal Selection and Primary and Secondary Immune Responses

As already stated, each B and T lymphocyte displays on its surface a specific receptor; the number of cells expressing a given receptor is rather small. In case of a B cell, this receptor is the antibody produced by that cell. When this receptor interacts with the antigenic determinant specific to it, the lymphocyte becomes activated and divides to form a clone of cells. These cells are also transformed into effector cells, i.e., antibody producing B cells and T cytotoxic cells. This phenomenon is called **clonal selection**, where all the cells in a given T or B cell clone are derived from a single parental cell, and exhibit the same specificity for antigenic determinant. But some of the activated lymphocytes develop into long-lived **memory cells**, and do not produce antibodies or kill infected cells. However, they divide and produce antibody whenever they get further encounter from the same antigen.

The immune response mounted as a result of the first encounter of an animal with an antigen takes relatively longer, is feeble, and declines rapidly. This is known as **primary immune response**. But a subsequent encounter of this animal with the same antigen results in a hightened immune response much more rapidly. This is referred to as the **secondary immune response**. The secondary response is due to the **memory cells** that were produced during the primary response; it lasts much longer than primary response. This is why a person surviving a disease like chicken pox or measles becomes immune to subsequent attacks of the same disease.

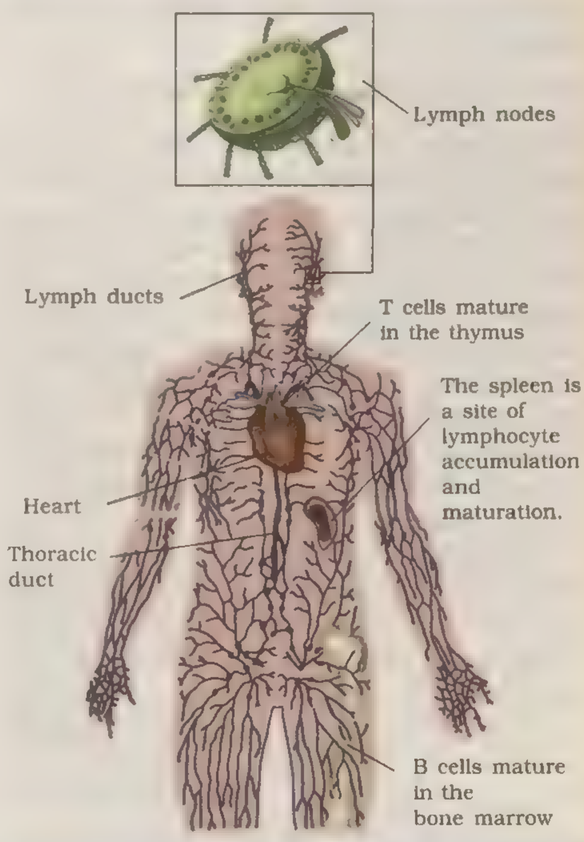


Fig. 25.6 Human lymphatic system

25.4 Lymphoid Organs

Lymphoid organs are those organs where the maturation and proliferation of lymphocytes take place (Fig. 25.6). There are two types of lymphoid organs. The **primary lymphoid organs** are those sites where T and B lymphocytes mature, and acquire their antigen-specific receptors. Bone marrow (site of B cell maturation) and thymus (site of T cell maturation) constitute the primary lymphoid organs. After maturation, B and T cells migrate via the circulatory system (blood vascular and lymphatic systems) to the **secondary lymphoid organs**. These include lymph nodes, spleen and mucosa-associated lymphoid tissues, such as tonsils. These organs are the sites for proliferation and differentiation of lymphocytes, in response to specific antigens. The acquired immune response to antigens usually develops in these organs.

25.5 Vaccination and Immunisation

The principle of immunisation or vaccination is based on the property of "memory" of the immune system. In vaccination, a preparation of antigenic proteins of pathogens or inactivated/weakened pathogens (vaccine) is introduced into the body. These antigens generate the primary immune response, and the memory B and T cells. When the vaccinated person is attacked by the same pathogen, the existing memory T or B cells recognise the antigen quickly and overwhelm the invaders with a massive production of lymphocytes and antibodies.

Edward Jenner, an English physician, in his landmark experiment in 1796, scratched the skin of a boy to introduce into his body the fluid from a sore of a milkmaid who was suffering from cow pox. When the person was later exposed to smallpox, he showed resistance to the disease. Louis Pasteur, a French scientist, found that ageing cultures of cholera bacteria were too weak to cause disease when injected into chickens. But chickens injected with these cultures became immune to fowl-cholera (Fig. 25.7). Using this method,

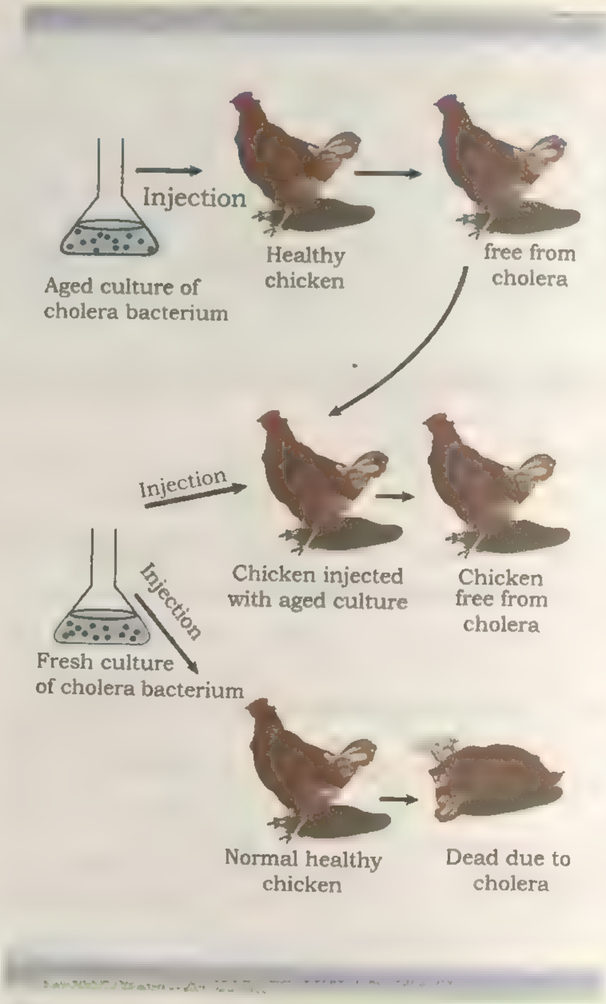


Fig. 25.7 *The classic experiment of Pasteur with chicken (fowl) cholera*

Pasteur developed a vaccine (Latin, *vacca*, meaning : cow) against rabies in 1885. It was later discovered that animals injected with small amounts of the tetanus toxin became immune to the disease. By the end of 1920s, vaccines for diphtheria, tetanus, pertussis (whooping cough) and tuberculosis were available.

Some examples of common vaccines are listed in Table 25.2. Traditionally, the vaccine preparations contained either inactivated pathogens, or live but weakened pathogens. Subsequently, antigenic polypeptides prepared from pathogens were used in vaccines. Recombinant DNA technology has allowed the production of antigenic polypeptides of

Table 25.2 : Important Vaccines for Babies and Children

Vaccine	Disease	Age group	Safety
DTP-Hib	Diphtheria, Tetanus, Pertussis (whooping cough) and *Haemophilus influenzae* type B	All babies of 1½, 2½ and 3½ month age	Between 90 and 99%
Hepatitis B	Hepatitis	All babies whose mothers or close family have been infected with hepatitis B	Not yet known
Polio	Polio	All babies of 1½, 2½ and 3½ month age at the same time as DTP-Hib.	Almost 100%
BCG	tuberculosis (TB)	All children between 10 and 14 years	70%

pathogens in transgenic organisms. Some vaccines produced using this approach are now available, e.g., hepatitis B vaccine produced from transgenic yeast. Attempts are being made to use suitable preparations of the concerned genes themselves from the pathogens as vaccines.

25.6 Blood Groups

There are 30 or so known antigens on the surface of red blood cells that give rise to different blood groups. In a transfusion, certain blood groups, e.g., ABO blood group, of the recipient and donor must be matched, otherwise the recipient's immune system will produce antibodies causing agglutination of the transfused cells and blocking circulation through capillaries.

ABO blood groups are determined by the gene *I* (for isoagglutinin). There are three alleles, I^A, I^B and I^O of this gene. Proteins produced by the I^A and I^B alleles are known as A and B antigens, respectively. Individuals with blood group A have the A antigen on the surface of their red blood cells (RBCs), and antibodies to antigen B in their plasma. People with blood group B have B antigen on their RBCs, and antibodies against A antigen in their plasma. Individuals with AB blood group have both antigens A and B on their RBCs, and no antibodies for either of the antigens in their plasma. Type O individuals lack A and B antigens on their RBCs, but have antibodies for both these antigens in their plasma. People with blood group AB can receive blood of A, B or O group, while those with blood group O can donate blood to anyone. This is the most important blood group in transfusion. If a transfusion is made between an incompatible donor and recipient, reaction of antigens on the cells and antibodies in the plasma will produce clots that will clog capillaries.

The Rh (Rhesus) blood group is due to a cell surface antigen, which was first discovered in rhesus monkey. Persons having this antigen are called Rh positive (Rh^+), whereas Rh negative (Rh^-) individuals lack this antigen. Rh antigen induces a strong immunogenic response when introduced into Rh^- individuals. Rh blood group is important in blood transfusion, and is involved in haemolytic disease of the newborn (HDN). When an Rh^- mother bears an Rh^+ foetus, the Rh^+ RBCs from the foetus may enter the mother's circulatory system during child birth, causing her to produce anti-Rh antibodies. As a result, subsequent Rh^+ foetuses will be exposed to the anti-Rh antibodies produced by the mother, which results in HDN. In order to prevent HDN, Rh^- mothers are injected with a anti-Rh-antibody during all pregnancies carrying Rh^+ foetus.

25.7 Organ Transplants and Antibodies

Success of organ transplants and skin grafts depends on a proper matching of histocompatibility antigens that occur on all cells of the body. Chromosome 6 of mouse contains a cluster of genes known as the **major histocompatibility complex (MHC)**, which in humans is called **human leukocyte antigen** (HLA) complex. The alleles of HLA genes are codominant. The products of these genes determine histocompatibility, i.e., compatability between donor and recipient tissues in transplants. The array of HLA alleles on a homologue of our chromosome 6 is known as a **haplotype**. An individual inherits one HLA haplotype from each parent. The large number of alleles at this locus ensures that only identical twins have the identical haplotype. The best HLA matches would occur within a family. Therefore, the preference order for transplants is as follows : identical twin > sibling > parent > unrelated donor.

The procedure carried out to match HLA proteins of donor and recipient is called **tissue typing**. When HLA types are matched properly, the survival of transplanted organs increases dramatically.

25.8 Immune System Disorders

Clearly, the immune system is a multicomponent interactive system. It effectively protects the host from various infections. But an improper functioning of the immune system can cause discomfort, disease or even death. The improper functions fall into the following major groups : (a) hypersensitivity or allergy, (b) auto-immune diseases, and (c) immunodeficiency.

Hypersensitivity

Allergies result from an inappropriate and excessive immune response to common antigens. Substances that cause allergies are called **allergens**; they include dust, moulds, pollen, certain foods, and some medicines such as penicillin. Allergy involves mainly IgE antibodies and histamine. A common manifestation of allergy is asthma. Sometimes an allergen may cause a sudden, violent and fatal reaction in a sensitive individual; this is called **anaphylaxis**.

Autoimmune Diseases

Autoimmune diseases result when the immune system attacks and destroys "self" cells and molecules. This condition can cause chronic and serious diseases. Examples of autoimmune diseases are insulin-dependent diabetes, multiple sclerosis, rheumatoid arthritis, etc. **Multiple sclerosis** is caused by antibodies that attack the myelin sheath of nerve cells.

Immunodeficiency Diseases

Immunodeficiency diseases result from a defect in one or more components of the innate or adaptive immunity. Affected individuals are susceptible to diseases that normally would not bother most people. Immunodeficiency may result from gene mutations, infections, malnutrition or accidents. **Severe combined immunodeficiency** (SCID) results from one of many genetic defects; one such genetic defect leads to adenosine deaminase deficiency. SCID is characterised by a very low number of circulating lymphocytes. Affected individuals usually die at an early age. AIDS is an example

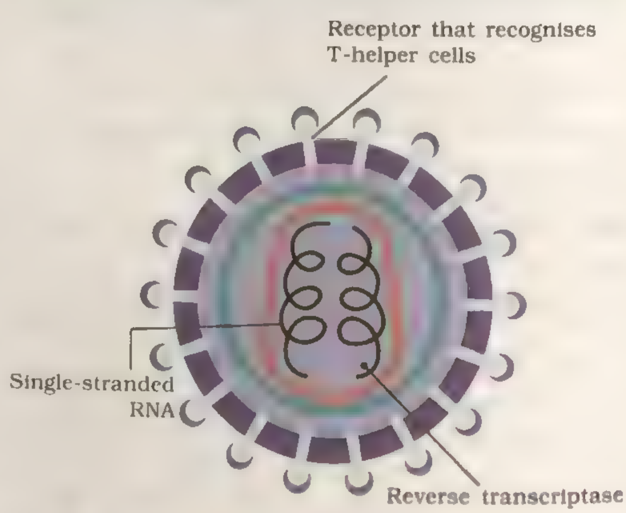


Fig. 25.8 Schematic representation of HIV

of immunodeficiency disease caused by the infection from a retrovirus, known as **human immunodeficiency virus** (HIV) (Fig. 25.8). Retroviruses have RNA genomes that replicate via DNA intermediate. HIV selectively infects and kills T-helper cells. The depletion of T-helper cells weakens the acquired immune response, and may even abolish it completely. The viral RNA genome is converted into DNA copy by the viral enzyme reverse transcriptase. The DNA copy of HIV becomes inserted into the human chromosome and replicates with the cellular DNA. It may be transcribed to produce RNA copies of the viral genome. The RNA copies are packaged and liberated as virus particles. The infected cell is lysed in this process, and the released virus particles infect new T-helper cells.

SUMMARY

Animal body has elaborate mechanisms for protection from foreign agents and cancer cells (immunity). Immunity is either innate or acquired. Innate or non-specific immunity comprises those mechanisms that are always available to protect animal body, i.e., previous exposure to an antigen is not needed to activate these mechanisms. These mechanisms consist of anatomic, physiologic, phagocytic and inflammatory barriers. Innate immunity is the first line of defence of most animals and plants. Acquired immunity (also called adaptive or specific immunity) is found only in vertebrates. It has the ability to recognise and selectively eliminate specific foreign agents. It is initiated in response to an exposure to the foreign agent in question, and the process takes several days. Acquired immunity has the following unique features : (i) specificity, (ii) diversity, (iii) memory, and (iv) discrimination between self and non-self. It is of two types, viz., active (immune response generated in the concerned individual) and passive (transfer of antibodies, etc. from another individual into a non-immunised individual).

Acquired immunity employs two major groups of cells, viz., lymphocytes and antigen presenting cells. Lymphocytes are of two types : (a) B lymphocytes (mature in bone marrow and produce antibodies) and (b) T lymphocytes (mature in thymus and function as cytotoxic or helper cells). Both B and T cells display on their surfaces specific receptors that interact with the antigens.

The antigen is processed by antigen presenting cells and its fragments are displayed on the surface of these cells. T helper cells interact with the presented antigen and become activated. These T cells, in turn, activate specific B and T cytotoxic cells. Activated B and T cells proliferate to form clones (clonal selection); some of these cells function in immune response, while some others become memory cells (responsible for secondary response and vaccination). B cells produce antibodies, while T cells kill the target cells (infected cells, cancer cells).

Antibodies are glycoproteins (immunoglobulins). Each antibody has two light chains and two heavy chains that form a Y-shaped structure. The top two tips of this Y specifically interact with the antigen to form antigen-antibody complex. Antibodies are grouped into the following five classes : IgA, IgD, IgE, IgG and IgM.

The property of 'memory' of immune system is used in vaccination. The vaccine consists of a preparation of antigenic proteins of pathogens, or weakened/inactivated pathogens themselves. The antigenic protein may be prepared from the pathogen, or produced in a transgenic organism, e.g.,

hepatitis B vaccine produced in yeast. Vaccination has its origin from the works of Edward Jenner and Louis Pasteur. Some examples of commonly used vaccines are BCG, DPT-Hib, hepatitis B, polio etc.

Human blood cells display on their surface 30 or more different antigens. These antigens give rise to various blood groups, e.g., ABO, Rh, etc. blood groups. The success of organ transplant depends on proper matching of proteins, called human leucocyte antigens. The preference order for transplants is : identical twin > sibling > parent > unrelated donor.

An improper function of the immune system gives rise to the following groups of disorders : (i) allergy (excessive immune response to common antigens), (ii) auto immune diseases (the immune system attacks and destroys self cells and molecules), and (iii) immunodeficiency diseases (inability to mount immune response). Immunodeficiency may result from gene mutations (e.g., SCID), infections (e.g., by HIV), malnutrition or accidents. HIV is a retrovirus; it has a single-stranded RNA genome that is reverse transcribed and incorporated into the host genome. HIV specifically attacks T helper cells.

EXERCISES

1. Which of the following properties of acquired immunity is the basis of vaccination?

   (a) Specificity
   (b) Diversity
   (c) Memory
   (d) Discrimination between self and non-self.

2. Immunodeficiency can result from which of the following?

   (a) Gene mutation
   (b) Infection
   (c) Malnutrition
   (d) All of the above.

3. Match the components of the immune system given in column I with the phenomenon listed in column II.

Column I	Column II
(i) Histamines	(a) Antibody production
(ii) Complement proteins	(b) Activation of B cells
(iii) IgE	(c) Inflammatory response
(iv) T cytotoxic cells	(d) Processing of antigens
(v) B cells	(e) Passive immunity to foetus
(vi) T helper cells	(f) Pore formation
(vii) Antigen presenting cells	(g) Killing of specific target cells
(viii) IgG	(h) Allergy
(ix) IgM	

4. HIV attacks which of the following?
   (a) B cells
   (b) T cells
   (c) Antigen presenting cells
   (d) T helper cells.
5. Which of the following is not a component of innate immunity?
   (a) Antibodies
   (b) Interferons
   (c) Complement proteins
   (d) Phagocytes.
6. Define the following terms :
   (a) Innate immunity
   (b) Clonal selection
   (c) Acquired immunity
   (d) Immunology
   (e) Haematopoiesis
   (f) Antigen
   (g) Antigenic determinant
   (h) Vaccine
   (i) Primary immune response
   (j) Secondary immune response.
7. Explain the following in not more than 70 words.
   (a) Properties of acquired immunity
   (b) Activation of adaptive immunity
   (c) Role of lymphoid organs in immune response
   (d) ABO blood groups
   (e) Hypersensitivity
   (f) Autoimmune diseases
   (g) AIDS.
8. Explain the following in not more than 100 words.
   (a) Innate immunity
   (b) Rh blood groups
   (c) Organ transplants
   (d) Vaccination.
9. Explain the role of innate immunity in protection from infectious agents.
10. Explain the phenomenon of adaptive immunity with special reference to its properties, activation, clonal selection, and its role in vaccination.
11. Briefly explain the various types of disorders arising from improper function of the immune system.
12. Briefly explain the functions of the following with reference to immunity :
    (a) Antibodies
    (b) T helper cells
    (c) HLA proteins
    (d) B cells
    (e) Interferons
    (f) Mucous membranes
    (g) Phagocytes
    (h) Complement proteins

Chapter 26

Biomedical Technologies

Clinical doctors employ a number of simple instruments, such as clinical thermometer to monitor your body temperature, stethoscope to hear the natural sounds inside your body and so on. Technological developments have revolutionised the instruments used for disease diagnosis. Any modern hospital or clinic features a wide range of such devices. In this chapter, we will study about some of these diagnostic tools.

26.1 Diagnostic Images

A great deal can be learnt about our body by using X-rays and scanners. The images so obtained reveal defects and abnormalities, which aid in disease diagnosis.

X-Ray Radiography

X-rays (discovered by German physicist, Wilhelm Roentgen, in 1895) have a remarkable ability to penetrate matter. They are a vital diagnostic tool, providing detailed images of dense parts of the body, e.g., bones. A burst of X-radiation is aimed at the patient's undressed body part to be examined. Some of the radiations pass through the body and fall on a film containing X-ray sensitive emulsion. An image, called radiograph, which is a shadow of the dense parts of the body (Fig. 26.1), is obtained.

Fig. 26.1 *X-ray radiograph of chest*

Angiography

X-rays, when coupled with image intensifiers, provide real-time images. These images can be viewed continuously by CRT (cathode ray tube) video monitor during surgery. **Digital subtraction angiography** (DSA), is an imaging technique that produces clear views of flowing blood in vessels and indicates the presence of blockages, if any. An angiograph (*angeion* : vessel; *graphein* : to record) is taken of the organ, for example, heart and its major blood vessels, and stored in a computer. A second angiograph is taken after a contrast agent containing iodine, which is opaque to X-rays, has been injected into the blood stream. The first image is digitally subtracted from the

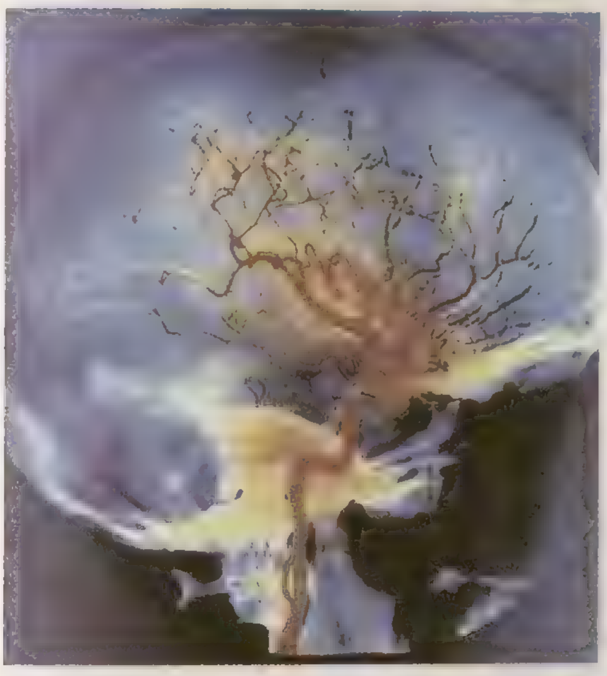


Fig. 26.2 *An angiograph of human brain*

Fig. 26.3 *CT scan of human brain*

second, leaving behind a clear outline of the blood flow to heart, brain (Fig. 26.2) or kidneys.

Computed Tomography

Simple radiography images are often difficult to interpret because, in them, a number of internal structures are superimposed, one on top of the other. A technique known as **computed tomography** (CT) or **computerised axial tomography** (CAT) was developed in 1972. This sensitive technique makes it possible to image the internal structures distinct from each other in a manner they would be seen in a thin section of the body (Fig. 26.3). For this invention, Godfry Hounsefield, a physicist, was awarded the Nobel Prize in 1978. The theoretical basis of this technique was provided by the work of the Indian biophysicist, Gopalsamudram N. Ramachandran.

During examination, a low dose X-ray beam moves 360° around and passes through a thin section of the body of the patient. The rays coming out of the body are recorded by a bank of sensitive detectors. This is repeated until the same body section has been examined from all angles. A computer analyses the data and reconstructs the images of the internal organs in this section of the body. Many slices can be "stacked" on video screen to form a three-dimensional (3D) view of a patient's internal organs. Doctors get a complete series of pictures showing slices through the body at slightly different planes. This helps them pinpoint small defects.

Magnetic Resonance Imaging

The **magnetic resonance imaging** (MRI) yields the best pictorial form and it does not expose the patient to potentially harmful ionising radiations. Felix Bloch and Edward M. Purcell shared Nobel Prize for Physics (1952) for developing the basic mechanism, which now forms the basis for MRI scanning.

MRI relies on the phenomenon known as **nuclear magnetic resonance** (NMR). Scientists picked hydrogen as the basis for MRI scanning because of its abundance in the body and its prominent magnetic qualities. The proton (nucleus of hydrogen atom : ^{1}H) carries an electric charge and behaves like a miniature magnet. Under normal conditions, human body has no overall magnetic field. For MRI, the patient lies in a supine position on a couch about 2 metres wide, surrounded by the coils of a giant cylindrical electromagnet. This magnet creates a magnetic field almost 70,000 times as strong as that of the Earth. This magnetic field orients the magnetic moment of the hydrogen nuclei in such a way that they can absorb electromagnetic radiation at a definite frequency. This frequency changes when the chemical environment of the hydrogen nuclei is changed.

MRI detects water because it focuses on the behaviour of hydrogen atoms in water molecules. This allows MRI to distinguish between water-poor and water-rich tissues. Teeth and bones, which contain little water, do not appear in MRI. Therefore, tissues surrounded by bones, such as spinal cord, are readily observable in MRI. It is used to detect tiny lesions of multiple sclerosis on brain and spinal tissue, and to examine joint injuries and slipped disk in the spinal column. MRI can also visualise minute cancerous tumours, since radiofrequency absorbed by the hydrogen atoms in such tissues for the same field is different from that for normal tissues. The MRI scan depicted in Figure 26.4 shows a brainstem tumour.

Fig. 26.4 *An MRI scan of human brain showing brainstem tumour*

Positron Emission Tomography

Positron emission tomography (PET) scanners monitor the consumption of a substance like glucose by neurons. The glucose is tagged with a radioisotope that has radioactive nuclei deficient in neutrons and with an excess of protons, e.g., ^{11}C and ^{15}O. A drip delivers a small amount of this radioactive glucose into the patient's blood stream, which gets distributed according to the physiological and biochemical needs of the various organs. As the radioactive atom decays, it emits a subatomic particle, called positron. Almost immediately, the emitted positron collides with its antiparticle, i.e., an electron. This collision annihilates them and releases a burst of electromagnetic energy in the form of a pair of γ-radiation. This double emission is the key to the PET scan. These radiations emerge simultaneously in the opposite directions and they strike crystals in a ring of detectors around the patient's head, causing the crystals to light up.

A computer records the location of each flash and spots the source of radiation, translating that data into a 3D-image. A metabolically active tissue will receive a greater blood supply than a relatively inactive tissue. Therefore, it will also get a greater supply of radioactive glucose, and would appear as a brighter area in the PET image. For example, the darkened area on the left side of brain in

Fig. 26.5 *A PET scan of human brain showing damage in left side from stroke Colour code : Red = active : Blue = least active*

Figure 26.5 indicates damage from a stroke. Bright colours in the rest of the brain show normal blood flow. Thus, by tracing the radioactive glucose, a physician can pinpoint the areas of greater brain activity, e.g., the regions of brain involved in a particular function. This versatile technique is used to study epilepsy, schizophrenia, Parkinson's disease and drug addiction.

Sonography

Sonography is based on ultrasound (frequency above 20 kHz). Ultrasound of frequency between 1 and 15 MHz is beamed into the human body, and the returning echoes are detected. The ultrasound waves pass through a homogenous tissue unimpeded. But when they meet another tissue or organ, a partial reflection takes place, the coefficient of

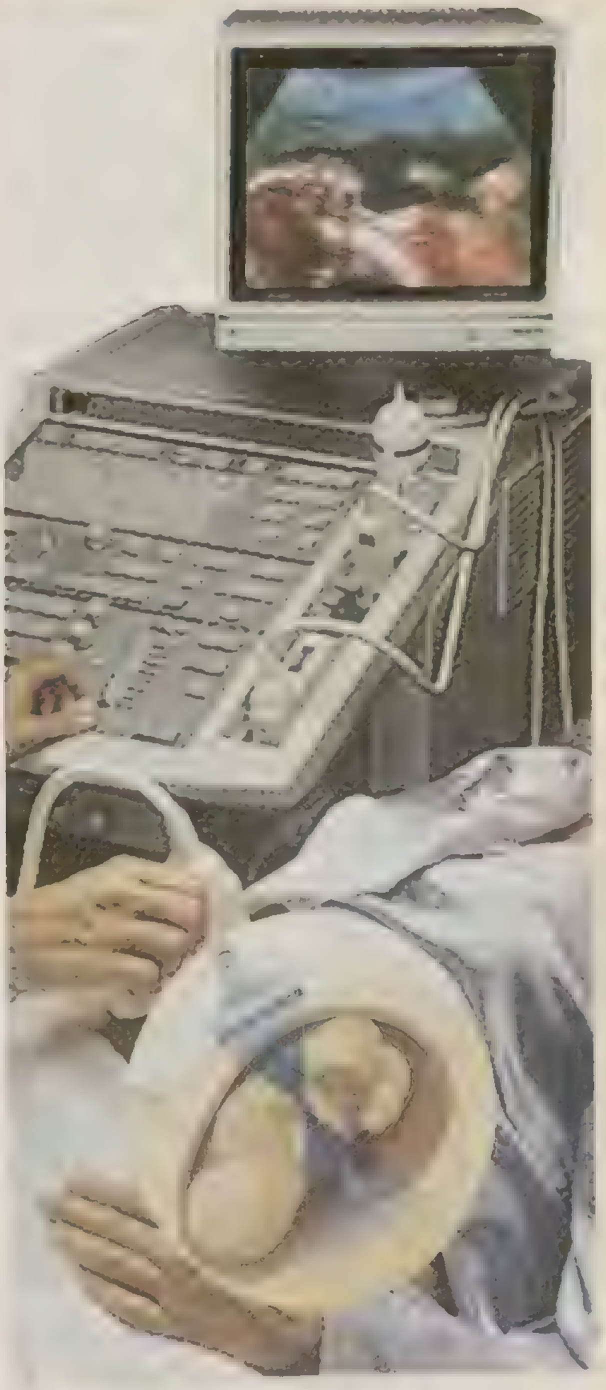


Fig. 26.6 *Sonography depicting a healthy foetus*

reflection depending upon the difference in densities of the two tissues/organs.

For clinical examination, a sonographer places a scan head transducer in contact with the area to be scanned. A layer of aqueous gel is applied between the skin and scan head to ensure that the sound has an air-free path to the object of interest, e.g., a foetus. A precise sequence of ultrasound waves penetrate the body, strike the organs within and reflect back to the surface, where the transducer now functions as a receiver. The echoes are processed by a computer into a video image. The time delays of these returning signals sketch the target's location, size, shape, and even its texture. Figure 26.6 shows the face of a healthy six month old foetus, with mouth open in a yawn.

Sonography, safer than radiography, is comfortable and inexpensive. It is used to assess foetal growth and to pick up a wide range of abnormalities, such as spina bifida, and conditions liable to cause difficulty in labour. Sonography is also used to image the adult body. It even provides pictures of blood flow through the beating heart, based on a phenomenon known as **Doppler effect** (Fig. 26.7).

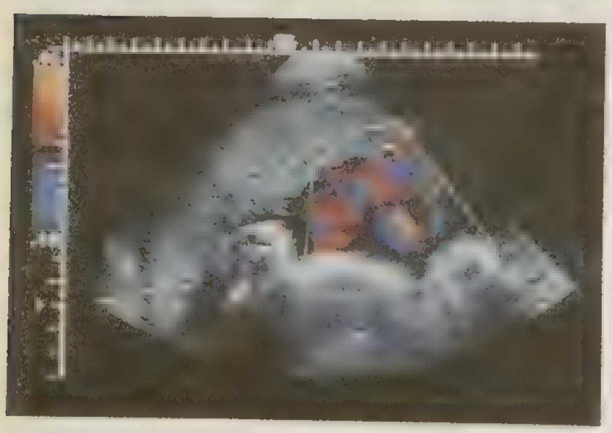


Fig. 26.7 *A colour sonograph using Doppler effect show blood flow through human heart. Red colour : blood flow towards the transducer; Blue colour : blood flow away from the transducer*

26.2 Monitoring of Body's Vital Functions

If you visit an intensive care unit of a modern hospital, you will find a patient connected to life-support systems and a range of electronic sensors that continually monitor his/her vital signs. Their signal outputs, such as, heart rate, blood pressure, body temperature, oxygen level in the blood, etc., give continuous information about the patient's condition and warnings of developing problems. This can even help a physician to diagnose a disorder or disease.

You have already learnt that the human body is alive with electrical activity. Nerve cells carry information around the brain and body in the form of action potentials. Similarly, when a muscle contracts, each of its component fibres produces an action potential. In both cases, the action potentials produce measurable electrical signals that can be detected at the surface of the body by sensitive electronic circuits called **biopotential amplifiers.**

Electrocardiography

Electrocardiography reads the electrical signs produced by nerves and muscles in the beating heart and records them as an **electrocardiogram** (ECG). The simplest type of ECG monitor is a cardioscope. Three electrodes are connected via a conductive electrolyte gel to the patient for detecting tiny electrical signals. Two of the electrodes are on the chest above the heart, and the third is a "reference" connection to the limbs. The signal collected is only a few millivolts at the skin surface. It is amplified before being displayed on a CRT oscilloscope screen, or recorded on a sensitive chart recorder.

You have learnt in Chapter 7 that the waves of ECG are designated as P, Q, R, S and T, each letter representing a particular event in the cardiac muscle (Fig. 26.8). Each part of the cardiac cycle produces its own characteristic spike on the cardioscope display. In some types of heart disease, the distance between the first (corresponding to atrial contraction) and the second (ventricular contraction) spikes is noticeably greater than

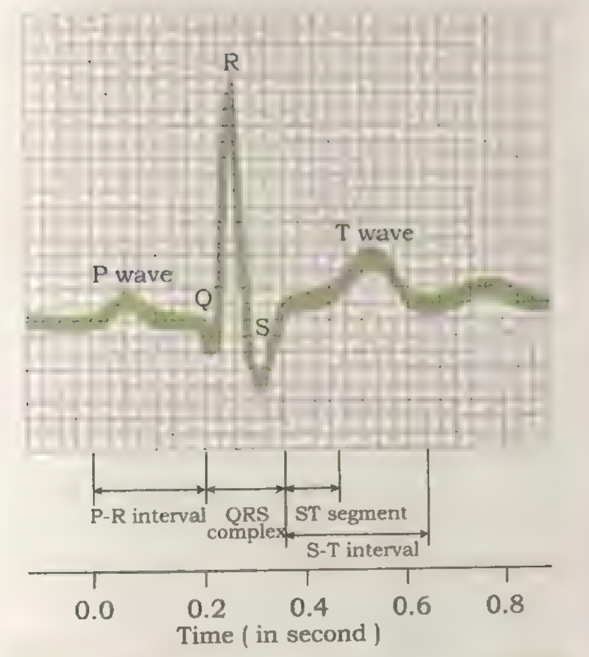


Fig. 26.8 *Electrocardiogram*

normal. This observation suggests that the nerve bundles that coordinate the contraction of the atria and ventricles, are dispersed by inflammation or infection. The more sophisticated diagnostic electrocardiograph uses a dozen or more electrodes, placed at 6 different positions on the chest to provide a 3D "map" of the heart's electrical activity.

ECG reveals the rate of heartbeat, and can help diagnose heart disorders following a cardiac arrest (myocardial infarction), deviations from normal pattern of heartbeat, coronary artery diseases, etc.

Electroencephalography

A similar technique, called **electroencephalography**, measures and maps transient electrical signals generated by neuronal depolarisation in the brain, and records this as an **electroencephalogram** (EEG). In EEG, 16 to 30 equally spaced electrodes are stuck to the patient's scalp and connected to an amplifier. The patterns of electrical activities are traced out as wavy lines on a moving sheet (Fig. 26.9) of graph paper, or displayed on a computer screen.

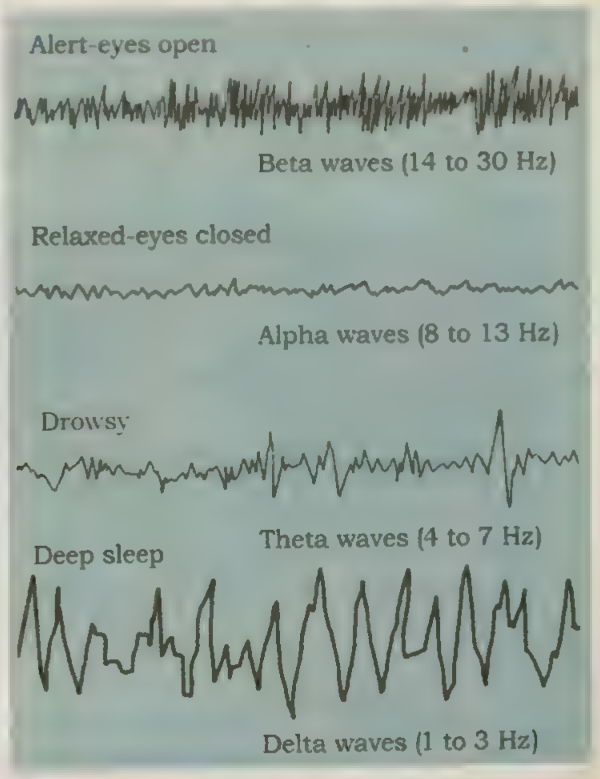


Fig. 26.9 *Electroencephalogram*

A typical recording takes 30 to 60 minutes. At any instant, the electrical signals, known as brain waves, on the surface of the brain, result from the synchronised activity of millions of neurons of the cerebral cortex. They are detected on the scalp and amplified about one million times before display. Although EEG traces lack the regular appearance of the ECG, their component waves can be recognised by an experienced operator. Low-frequency rhythms, called alpha waves, are present when the brain is in a relaxed state. During drowsiness or sleep, these waves are replaced by lower-frequency theta and delta waves. Theta waves normally occur in persons experiencing emotional stress. Delta waves occur during deep sleep. Higher-frequency beta waves

are associated with mental activity in frontal areas of the brain, and during periods of sensory stimulations.

The EEG is used to map regions of abnormal brain activity associated with tumours, trauma, hematomas, epilepsy and other seizure disorders and periods of unconsciousness and confusion. This is also used to identify the incidence of "brain death", the complete absence of brain waves in two EEGs taken 24 hours apart.

Polygraphy

Polygraph is a relatively simple, compact and often portable machine that records qualitative changes in physiological parameters, rather than measuring them accurately. These parameters include vital traces, such as cardiac variables (ECG), heart pulse rate (HR), relative blood pressure (BP), the rate and depth of breathing, and the resistance of skin to the conduction of electricity, and so on. It is popularly, but quite incorrectly, called "the lie detector". A modern computerised version of this multi-channel device is used to record neurophysiological parameters, such as EEG, EMG (electromyograph), EOG (electrooculograph). The main applications of this device are lie detecting, monitoring of stages of sleep, and electrophysiological behaviour of the brain and its dysfunctions.

26.3 Biochemical Autoanalysers

It is a multi-channel, fully temperature-regulated and computer-controlled equipment. It can analyse hundreds of samples of body fluids, like blood serum or cerebrospinal fluid (CSF), within a short time. Samples are introduced at regular intervals in a sequential manner through a network of micropipettes. The reagents are mixed with the sample in optically transparent cuvettes. Semi-automated analysers can estimate only one parameter at a time, e.g., glucose, cholesterol, urea, electrolytes, etc. But sophisticated analysers can analyse simultaneously 40, or even more, parameters in a single sample; the number of parameters analysed is, however, selected by the operator.

26.4 Diagnostic Kits

Diagnostic kits are based on enzyme activities, antigen-antibody interaction, or nucleic acid hybridisation. We will briefly consider ELISA (enzyme linked immunosorbent assay), which detects the presence of an antigen or antibody in a sample by antigen-antibody interaction. The principle and procedure of ELISA is as follows. Antibody specific to the antigen to be detected, must be available for ELISA. The sample suspected to contain the antigen is

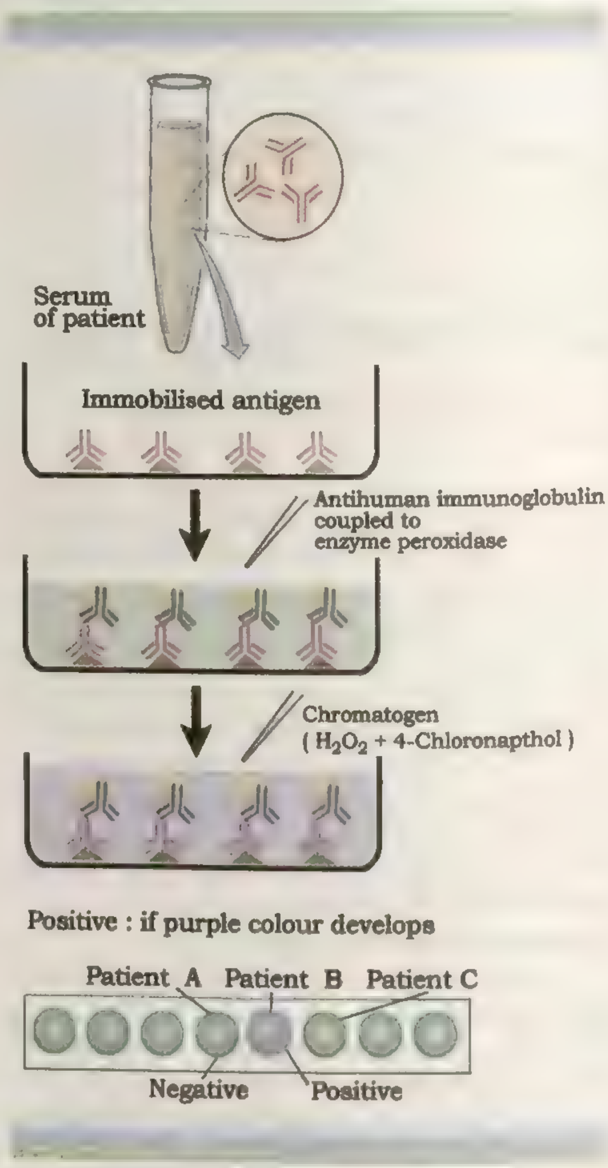


Fig. 26.10 Enzyme-linked immunosorbent assay (ELISA)

immobilised on the surface of a petriplate or an ELISA plate. The antibody specific to this antigen is now added and allowed to react with the immobilised antigen. Unreacted antibody molecules are washed away, leaving only those antibody molecules that are bound to the antigen. Now, an anti-immunoglobulin is added and allowed to react with the antibody bound to the antigen. This anti-antibody is linked to an appropriate enzyme, e.g., peroxidase. The unreacted anti-antibody is washed away, and the substrate of the enzyme is added along with the necessary reagents. Activity of the enzyme yields a coloured product (Fig. 26.10). The intensity of colour is directly proportional to the amount of the antigen. ELISA is highly sensitive, and can detect antigens in the range of nanograms. It is a very rapid assay, and is applicable to a variety of antigens.

26.5 Endoscopy

Using an endoscope (*endo* : within; *skopein* : view), a surgeon is able to carry out minor operations, without cutting through overlying tissues. The endoscope (Fig. 26.11) consists of a long flexible tube attached to a handset. The tube is inserted through an opening into the body, and its tip is "steered" to its destination. Bundles of optical fibres inside the endoscope transmit light to the tip. An image is formed on an array of light sensitive cells, called charge coupled device (CCD), at the tip; the electrical signal is sent up the tube along an electrical cable and fed into a videomonitor where a magnified image is seen. One channel in the endoscope carries water and air, making it possible to wash and dry the surgical site. Miniature surgical instruments, such as forceps, that are controlled by a cable running through a parallel channel, can also be taken to the site where surgery is needed. A wide variety of instruments can be fitted to the endoscope : toothed biopsy forceps allow samples of tissue to be removed for analysis; metal "snares" carry high-frequency electric current that can coagulate blood vessels.

Endoscopes are named after the part of the body they are designed to view. For instance, a gastroscope is used to examine the stomach for an ulcer, a laparoscope to detect cysts or infections of the uterus, fallopian tube and ovaries, and so on.

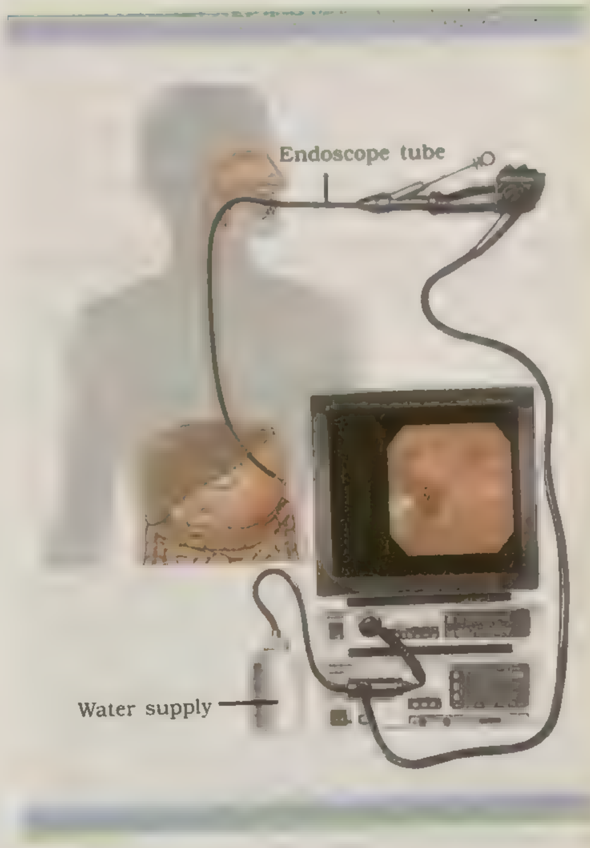


Fig. 26.11 Endoscopy

26.6 Laser Microsurgery

The effect of laser on tissue depends on its wavelength. This is determined by the type of laser used. For example, light from a carbondioxide laser has a wavelength of 10.6 μm; it is absorbed by water in the target cells, and its energy is quickly converted into heat. As a result, the effect of laser light is highly localised. Neurosurgeons use such a laser to remove otherwise inoperable brain tumours, where the slightest damage to the adjacent nervous tissue would prove catastrophic. The visible argon-ion laser has an intermediate effect on tissue, and is often used in eye surgery.

26.7 Cancer and Therapy

Death toll from infectious diseases is decreasing, making cancer a major cause of

death in the modern world. Therefore, it is essential to understand the biology of cancer cells. Cancer results from a breakdown of the regulatory mechanisms that govern normal cell behaviour. Thus, this disease has to be ultimately understood at the molecular and cellular levels.

How Cancer Cells Differ from Normal Cells?

Cell division is a highly regulated process, with a balance being maintained between production of new cells and cell death in most of the tissues and organs. Mature and differentiated normal cells have a finite life span. They are usually replaced by new cells generated by cell division and differentiation. Normally, the production of new cells is regulated in such a manner that at any given time, the number of a given cell type remains nearly constant. Normal cells live in a complex interdependent manner, regulating one another's proliferation. Occasionally, some cells may arise, which do not respond to normal growth control mechanisms. These cells proliferate in an unregulated manner, and give rise to clones of cells that can expand to a considerable size; this growth is called **tumour**.

All tumours are not malignant. Noncancerous tumours, commonly called **benign tumours**, remain confined to their original location and are incapable of indefinite growth, e.g., warts. However, **malignant tumours** grow rapidly, with infinite life span of the proliferating cells, and become progressively invasive. Only the malignant tumours are properly referred to as true cancer or **neoplasm**.

Properties of Cancer Cells

Cancer cells exhibit some of the following features, which distinguish them from normal cells. They show uncontrolled proliferative ability, with a reduced requirement for extracellular growth factors. They acquire the ability to invade new sites, a phenomenon designated as **metastasis** (Fig. 26.12). Cancer cells exhibit a number of alterations on cell surface, in the cytoplasm, and in their genes; these features are used for the identification of cancers. The ability of cancer cells to resist induction of cell death promotes the development of tumours.

Fig. 26.12 *Stages in development of cancer (a) to (d). Primary tumour may become metastatic and get transformed into secondary tumour*

Types of Cancer

Cancers are classified on the basis of the tissue of origin from where they arose. Most of the cancers fall into one of the following categories :

Carcinomas : Cancers of this type arise from epithelial tissues, such as skin or the epithelial lining of internal organs or glands (about 85 per cent of all tumours).

Melanomas : These are cancerous growths of melanocytes (a type of skin cells).

Sarcomas : These are derived from tissues of mesodermal origin, e.g., bone, fat and cartilage. They are rare in humans (about 1 per cent of all tumours).

Leukemias and lymphomas : These are tumours of the haematopoietic cells.

Causes of Cancer

Chemical or physical agents that can cause cancer are known as **carcinogens**. Depending on their mode of action, carcinogens fall into the following main categories :

(i) Agents that can cause alterations in the genetic material (DNA), resulting in **oncogenic transformation** that can lead to cancer, e.g., various types of radiations, and chemicals.

(ii) Agents that promote the proliferation of cells, which have already undergone genetic alterations responsible for oncogenic transformation. These agents are called **tumour promoters**, e.g., some growth factors and hormones.

(iii) Cancer causing DNA and RNA viruses (**tumour viruses**) have been shown to be associated with oncogenic transformation.

Cancer and Genes

Normal cell growth is under the control of some critical regulatory genes, which regulate cell proliferation, differentiation and survival. Alterations in these genes lead to oncogenic transformation. Cancer-associated genes can be divided into the following three categories :

(i) Genes that induce cellular proliferation, e.g., genes encoding growth factors, growth factor receptors, transcription factors, etc.

(ii) Genes that inhibit cellular proliferation (tumour suppressor genes).

(iii) Genes that regulate programmed cell death.

All these genes are involved in normal growth. Cancer is caused by mutant alleles of these genes, whose products do not respond to normal regulatory signals. As a result, the mutated cell proliferates uncontrollably.

How Cancer Spreads

Tumour growth starts in one location where an altered cell proliferates, giving rise to a clone of proliferative cells. This excessive proliferation gives rise to a mass of cells, initially known as benign tumour. The tumour cells enter into blood vessels and get spread at secondary locations; such tumour cells are known as **malignant cells**.

Detection and Diagnosis

Cancer diagnosis is based on the characteristic histological features of malignant cells. Blood tests for abnormal WBCs and bone marrow biopsy are also used. Non-invasive techniques, like X-ray (using injected dyes), CT scans and MRI scans can be used to detect cancers of internal organs like kidneys and pancreas. Modern techniques monitor and detect the molecular changes that occur in cancer cells; this enables an early diagnosis of cancer. Monoclonal antibodies against cancer-specific antigens are coupled to appropriate radioisotopes. These antibodies are then used for detection of cancer.

Treatment of Cancer

Various approaches have been adapted for the treatment of cancer. Therapeutic strategies vary, depending on the etiology of each individual cancer. Some of the common approaches include: (i) surgery, (ii) radiotherapy, (iii) chemotherapy, and (iv) immunotherapy. These therapies can be used either singly, or in a suitable combination.

Surgery : Surgical manipulation/excision of tumour mass is one of the easiest approaches in the treatment of cancer. However, surgery does not ensure that all the cancer cells have been removed. Moreover, not all tumours are accessible for surgical manipulation. Surgical reduction of tumour load is also considered advantageous prior to initiation of other therapeutic approaches.

Radiation therapy : This approach focuses on lethally irradiating cells in a tumour mass. However, this approach also causes tremendous damage to several tissues in the vicinity of tumour mass.

Chemotherapy : Several chemotherapeutic drugs are used in this strategy to kill tumour cells. Some such drugs can specifically kill tumour cells. However, majority of them have a number of side-effects.

Immunotherapy : One of the recent approaches of cancer treatment involves augmentation of natural anti-cancer immunological defence mechanisms. Monoclonal antibodies have been used in various ways, e.g., radioimmunotherapy, etc., for treatment of cancer. Research is in progress to develop cancer vaccines.

26.8 Transplantation

It involves the replacement of an injured or diseased tissue or organ, such as skin, cornea; heart, lung, kidney, liver, bone marrow, blood and pancreas. The success of organ transplants depends mainly on a proper matching of the antigens encoded by **major histocompatability complex** (MHC) or **human leucocyte antigen** (HLA) complex loci of the recipient and donor tissues (see Chapter 25). The most successful transplants are **autografts** (autologous graft) : transplants in which one's own tissue is grafted to another part of the body. **Isografts** are transplants in which the donor and recipient are genetically identical, e.g., graft between identical twins. An **allograft** (allogenic graft) is a transplant between individuals of the same species, but with different MHC/HLA alleles. The success of allograft depends on the degree of matching of MHC/HLA alleles, and on administration of immunosuppressive drugs, such as cyclosporin A, to inhibit the immunological mechanisms responsible for graft rejection. However, withdrawal of the immunosuppressive treatment may result in graft rejection. A **xenograft** is a transplant between animals of different species. This type of transplantation is used only when human grafts are not available.

26.9 Haemodialysis

If the kidneys are so impaired by disease or injury that they are unable to excrete nitrogenous wastes and regulate pH, electrolyte level, etc. of the plasma, the blood must be cleaned by an artificial device. This is called **haemodialysis** (Fig. 26.13). Dialysis means the separation of large particles from smaller ones by using a selectively permeable membrane. One of the best devices

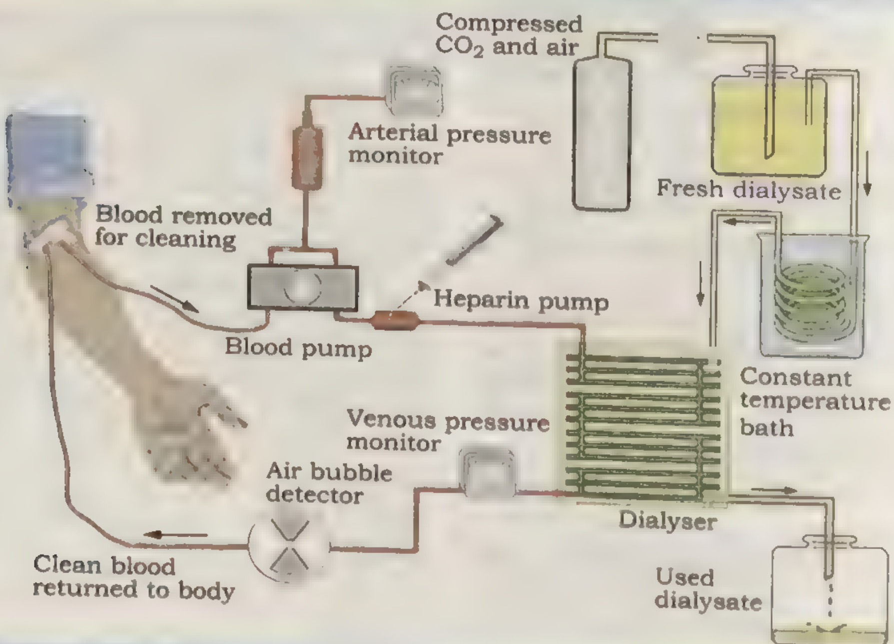


Fig. 26.13 *Haemodialysis machine*

for dialysis is the artificial kidney machine. A tube connects this machine with the patient's radial artery. The blood flows through the tubing, and waste products, such as urea and creatinine, pass from the blood into the dialysis solution surrounding the dialysis membrane. After passing through the dialysis tubing, the blood flows back into the body of the patient. In this way, the blood is purified to the standard level.

26.10 Prosthesis

Prosthetics is the branch of modern surgery that deals with prosthesis, i.e., implanting of an artificial substitute for a body part within the body. Internal replacements include intra-ocular lens fabricated to resemble the remaining eye in colour and configuration, nose implant for cosmetic reshaping, in-the-ear electronic hearing aids, etc. External prosthesis is exemplified by artificial arm or leg for a person who has undergone amputation. Successful Jaipur Foot made of vulcanised rubber, wood and aluminium by Dr. P.K. Sethi, is a remarkable achievement (Fig. 26.14).

Fig. 26.14 *Prosthetic Jaipur Foot*

Heart-Lung Machine

Once the heart is exposed in open heart surgery, circulation and respiration are maintained by heart-lung machine. The function of heart is performed by a roller pump, whereas the oxygenation of blood is carried out by an oxygenator that acts as artificial lung. This machine completely takes over the functions of heart as well as lung, and the blood circulates through the body without passing through heart. This allows the surgeons to perform complex procedures (Fig. 26.15).

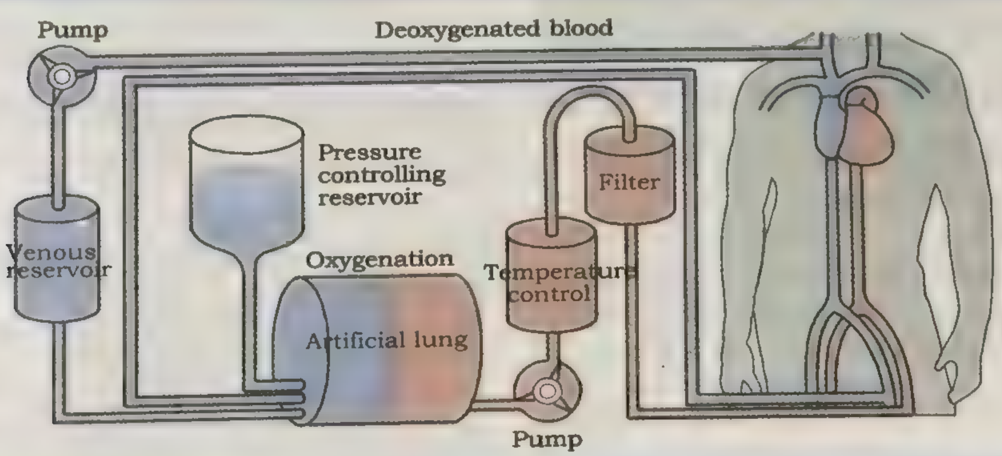


Fig. 26.15 *Heart-lung machine*

Prosthetic Cardiac Pacemaker

Cardiac pacemaker replaces the natural electrical stimulation of heart by a small electronic circuitry inserted substaneously in the upper thoracic region of the body (Fig. 26.16). Lithium composite battery provides power for about 10 years. It transmits repetitive electrical impulses to the heart in such a manner that the heart rate is maintained at a suitable level. If the heart operates normally, the mechanical pacemaker is inhibited.

Fig. 26.16 *Prosthetic cardiac pacemaker*

Defibrillator

Fibrillation is abnormal and asynchronous contraction of the heart muscles so that the effectiveness of heart pumping is reduced or completely lost. Atrial fibrillation may occur in myocardial infarction, and in rheumatic heart disease. A strong electrical current passed across the chest for a short period of time can stop ventricular fibrillation. This is called **defibrillation**. It is achieved by a defibrillator that gives the electric shock through large-paddle shaped electrodes pressed against the skin of the chest. Now, battery operated implantable devices are available for patients suffering from arrhythmic disorder.

Angioplasty (Balloon Catheterisation)

It is a technique for unblocking coronary arteries that have atherosclerotic plaque. A balloon catheter is inserted into an artery of the arm or thigh and gently guided

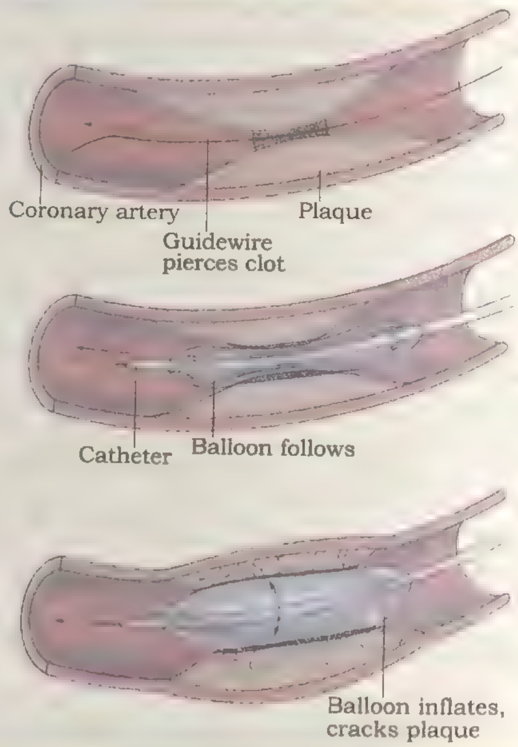


Fig. 26.17 *Balloon catheterisation*

through the arterial system under X-ray observation until it is threaded up into coronary artery (Fig. 26.17). Then, while dye is being released, angiograms are taken to localise the plaques. Next, the catheter is advanced to the point of obstruction and a balloon-like device is inflated with air to squash the plaques against the wall of the blood vessel, thereby clearing the channel for the

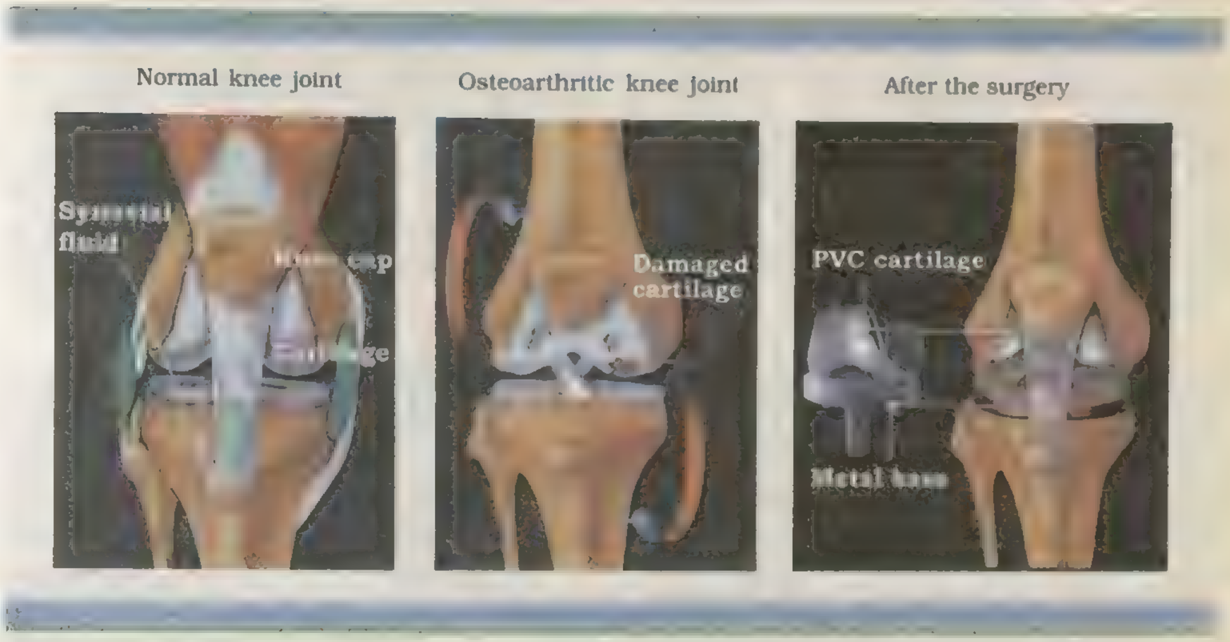


Fig. 26.18 *Knee joint replacement surgery*

blood, even in cases where it had previously been totally blocked.

26.11 Replacement Surgery

This type of surgery is done to replace prosthesis, following the removal of a damaged or diseased organ or a part of it. The part can be a hip or shoulder or elbow joint or knee (Fig. 26.18). Metal implants are biologically fixed to the desired location.

Vascular Graft

The leading causes of death are coronary thrombosis, stroke and cancer. For the treatment of coronary thrombosis, the damaged vessels have to be reconstructed. This is usually done by using a synthetic porous tube, made of Teflon or woven Dacron, as replacement of the diseased vessel or its segment. A special device called a **stent**, made of stainless steel, resembling a spring coil, can be permanently placed in an artery via a catheter (plastic tube). This is done to ensure adequate blood circulation through the artery to the heart muscles.

Coronary Artery Bypass Grafting (CABG)

It is a way of increasing the blood supply to the heart. In this surgical procedure, a blood vessel from another part of the body is used to bypass the blocked region of a coronary artery. The two vessels used most often are the saphenous vein from the leg, and the internal mammary artery from the chest.

26.12 Cryosurgery

Cryosurgery, as the name implies, uses freezing temperatures to destroy tissues. Liquid nitrogen, which has a boiling point of –196 °C, is sprayed onto the tissue either directly, as in the treatment of warts, or via a hollow probe that is inserted into the tissue. Cancerous tumours can also be destroyed in this way.

26.13 Immunotherapy

Immunotherapy is a treatment procedure that involves suppression or augmentation of immune responses, to achieve therapeutic effects. Manipulation of the immune response can be carried out by modulating various components involved in it. Cytokines are natural immunomodulators secreted by one type of immune cell that elicits response in another type of immune cell. These include interleukins, interferons and tumour necrosis factors.

Immunomodulators are, principally, drugs that modulate the activity of a patient's immune response, either up or down, until a desired level of therapeutic effect is reached. There are two general clinical approaches of immunomodulation.

(i) ***Immunopotentiation therapies*** : This includes administration of immunopotentiating agents like preformed antibodies, or immunopotentiating drugs. This strategy augments the immune response.

(ii) ***Immunosuppressive therapies*** : When the patient's immune system becomes activated against his or her own body, in situations such as, autoimmune diseases, the response is suppressed by using specific therapies. These include inhibitors of cell division, cytokine production, etc.

26.14 Hormone Therapy

Hormone-blocking and hormone-supplementing therapies have been used to treat various diseases involving hormonal deficiencies or imbalances. **Estrogen replacement therapy** is the most prescribed treatment for many of the complications of menopause. In this therapy, progesterone is usually taken with estrogen. But such patients, whose uterus has been surgically removed, may be given only estrogen.

26.15 Gene Therapy

Gene therapy is the introduction of a normal functional gene into cells that contain the defective allele of the gene, with the objective of correcting a disorder. The gene is inserted into a specially constructed vector, which is then introduced into somatic cells. Alternatively, it may be introduced into somatic cells either as a protein-DNA complex, or as naked DNA. Generally, the introduced functional gene is in addition to the defective gene present in the cells. Alternatively, it can replace the defective gene; this is most desirable, but quite problematic. Gene therapy has been employed to correct certain diseases like combined immune deficiency syndrome (SCID), with variable degrees of success. Attempts are being made to use gene therapy for combating dreaded diseases like cancer, heart attack, etc.

Gene therapy is still at experimental stages. It can be applied to only such diseases where the gene that plays the key role in disease has been identified and cloned.

26.16 Detection of HIV Infection

Usually, affected persons show symptoms of HIV infection within 2 to 6 weeks of exposure to the virus. But in some persons, the virus may remain silent for long periods (up to 10 years) before symptoms of full blown AIDS are observable. The symptoms of HIV infection include fever, lethargy, pharyngitis, nausea, headache, rashes, etc. Persons suffering from AIDS have a weakened immune system due to depletion of T helper cells. Such persons show **opportunistic infections**, i.e., infection by those fungi, bacteria and viruses to which a person with normal immune system is expected to be resistant. Therefore, persons prone to opportunistic infections may be suspected to be infected by HIV, particularly if the count of T helper cells is 200/mL or lower.

Infection by HIV is usually detected by ELISA. The presence of antibodies specific to HIV in the serum of suspected patients is detected by using a preparation of HIV proteins in the ELISA. The positive cases are subjected to western blot analysis for confirmation. In western blot assay, a preparation of HIV proteins is subjected to electrophoresis. The proteins are then transferred from the gel and fixed onto a nitrocellulose membrane. This membrane is incubated in the serum of the ELISA-positive patients, and antigen-antibody interaction is detected by using a labelled anti-antibody (in a manner similar to that of ELISA). This assay provides information on the specific HIV proteins for which antibodies are present in the serum of the patients. Antibodies against HIV appear after 2 to 12 weeks of infection by the virus, regardless of whether clinical symptoms are present or absent. In addition, suitable techniques may be used to detect the presence of viral genome in the blood of patients.

Table 26.1 : Some Important STDs and Common Techniques for their Detection

STD	Causal agent	Detection techniques
Chlamydia	*Chlamydia trachomatis*	Clinical, Gram-staining of discharge, antigen detection, nucleic acid hybridisation, Polymerase chain reaction (PCR)
Gonorrhoea	*Nisseria gonorrhoeae*	Gram-staining of discharge, culture
Trichomoniasis	*Trichomonas vaginalis*	Microscopic examination, culture
Genital Herpes	Herpes simplex virus	Clinical, antigen test, Polymerase chain reaction (PCR)
Syphilis	*Trepanoma pallidum*	Antibody detection,
Chancroid	*Haemophilus ducrei*	Clinical, culture
Genital warts	Human papilloma virus	Clinical, antibody detection, culture, DNA hybridisation (PCR)

26.17 Detection of Sexually Transmitted Diseases

Humans can suffer from over 30 different **sexually transmitted diseases** (STDs), including AIDS. Some of the important STDs are listed in Table 26.1. STDs are caused by bacteria, protozoa and viruses. Therefore, the technique employed for their detection depends primarily on the causal organism and the symptoms, etc. Clinical symptoms provide the initial indication of the type of STD. Confirmatory tests include culture, microscopic observation (usually following specific staining), detection of specific antigens/antibodies (by ELISA or some other approaches), DNA hybridisation and polymerase chain reaction (PCR). Culture allows the isolation, observation and identification of the causative organism. DNA hybridisation is based on labelled oligonucleotides (short polynucleotide sequences) that are complementary to a sequence specific to the genome of the concerned pathogen. PCR uses highly specific primers to amplify a sequence from the genome of the concerned pathogen to enable its definite detection and identification.

SUMMARY

Non-invasive imaging modalities, such as computed tomography (CT), magnetic resonance imaging (MRI), positron emission tomography (PET), ultrasound sonography, colour doppler, digital substraction angiography (DSA), provide 2D- or 3D-pictorial representation of the body parts. These are supported and aided by physiographs such as electrocardiographs (ECG) and electroencephalographs (EEG), that allow monitoring of functional status and diagnosis of ailments.

Invasive procedures, such as endoscopy, enable the doctor to view directly and/or indirectly body parts like bronchus, stomach, colon, urinary bladder, etc. A number of diagnostic kits based on recombinant DNA and hybridoma technologies, including ELISA and Western blots, are available for detection of cancers and pathogens responsible for AIDS, etc. Considerable progress

has been made in understanding the molecular basis of carcinogenesis. New therapies, such as selective drug targeting radiation, and surgical procedures are reducing the suffering of patients and prolonging their survival. Transplantations involving organ, tissue or even cells, are now feasible, because of surgical refinements and use in immunosuppressive drugs to overcome the problem of rejection. Advancement of biomaterial sciences and biomedical engineering has given an array of medical devices which include external and internal prosthetics in implants.

Immunomodulatory drugs and hormone replacement therapies may be used in the treatment of some such diseases that could not be properly managed earlier. Gene therapy is still in clinical trial stage, but it has enormous potential to treat genetic diseases and disorders.

Humans can also suffer from different sexually transmitted diseases (STDs), including AIDS. These diseases are diagnosed initially on the basis of clinical symptoms. The diagnosis is confirmed by one or more of the following tests : microscopic observation, culture, antigen/antibody detection, nucleic acid hybridisation, PCR, etc.

EXERCISES

1. Which of the following is cancer of blood?
   (a) Lymphoma
   (b) Leukemia
   (c) Myeloma
   (d) Sarcoma.
2. Which is the most appropriate imaging technique for investigating the functions of brain?
   (a) Magnetic resonance imaging
   (b) Computed tomography
   (c) Sonography
   (d) Positron emission tomography.
3. Metastasis is the process of :
   (a) Excessive cell proliferation.
   (b) Transformation of a benign tumour into a malignant tumour.
   (c) Movement of cancerous cells from one site to another sites in the body.
   (d) Transformation of a normal cell into a tumourous cell.
4. Prosthesis, that is designed to generate repetitive electrical impulses to the heart, is known as :
   (a) Artificial cardiac pacemaker
   (b) Heart-lung machine
   (c) Artificial heart valves
   (d) Intra-aortic balloon pump.
5. Current treatment for cancer does not include which of the following?
   (a) Chemotherapy
   (b) Radiation therapy
   (c) Surgery
   (d) Physiotherapy.

6. Mark true or false :
   (a) EEG reflects the generation of excitatory and inhibitory potentials in large number of neurons.
   (b) EEG demonstrates delta waves during relaxed consciousness.
   (c) ECG trace does not reveal the rate at which heart beats.
   (d) DSA is an imaging technique that produces clear views of flowing blood in the vessel and its blockade.
7. Write full forms of :
   (a) ECG, (b) EEG, (c) CT, (d) MRI, (e) PET, (f) ELISA.
8. What is the difference between invasive and non-invasive techniques in medical practice? Give one example of each.
9. Discuss the medical applications of EEG.
10. Briefly describe the principle of ultrasound and its medical applications.
11. What is the principle of MRI imaging? Describe the advantages of MRI.
12. Compare the information available from an electrocardiograph and an electroencephalograph.
13. What is a biochemical autoanalyser? How is it useful in medical diagnosis?
14. What is the principle of PET imaging? Describe briefly two important applications of this technique.
15. Briefly explain the medical application of LASERs.
16. What is prosthesis? How is cardiac pacemaker a life-saving instrument?
17. What is endoscopy? Briefly describe the medical applications of this technique.
18. What is the meaning and function of blood dialysis?
19. Briefly explain the principle and the function of ELISA.
20. Briefly describe organ transplantation and the approaches used to prevent graft rejection.
21. Briefly explain any one of the following : (a) gene therapy, (b) hormone therapy, and (c) immunotherapy.

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